NC STATE UNIVERSITY

Tacho Lycos
2015 NASA Student Launch
MAXI-MAV PDR

High Powered Rocketry Team
911 Oval Drive
Raleigh NC, 27695

November 5, 2014

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1.1. Team Summary

1.1.1. Name and Mailing Address

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1.1.2. Mentors

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1.2. Launch Vehicle Summary

1.2.1. Size and Mass

PDR	
Length	78 inches
Diameter	5.5 inches
Loaded Weight	15.25 lbs
Center of Pressure	57.9" from nose
Center of Gravity	47.4" from nose
Stability	1.9 cal
Apogee	3240 feet
Max Velocity	547 ft/s
Max Acceleration	266 ft/s^2
Recovery	1 Drogue/2 Main Parachutes
Motor	K535RR

1.2.2. Motor Choice

The club has selected the Animal Motor Works (Cesaroni) K535RR for the full scale motor. This motor provides a specific impulse of 324 lbf-s with a burn time of 2.7 seconds. This motor has an overall length of 15.9 inches and a diameter of 2.13 inches.

1.2.3. Recovery System

The vehicle will ultimately come down in two independent sections. At apogee, a 1.5 foot drogue parachute will deploy. This will separate the middle airframe and fin section from the upper airframe and nosecone. The drogue will be attached to an Advanced Retention Release Device (ARRD) in the upper airframe and to a bulkhead in the middle airframe. At 1100 feet, the ARRD will separate the nose cone and upper airframe from the middle airframe and fin section. Shortly after, at 1000 feet, the sample section and nose cone will separate releasing a 2.75 foot main parachute. In order to decrease the drift range, a 3.75 foot main parachute will deploy at 700 feet between the middle airframe and fin section.

1.2.4. Milestone Review Flysheet

The Milestone Review Flysheet can be found in the ***Appendix 1*** of this document. It can also be obtained from the Tacho Lycos website at www.ncsurocketry.com.

1.3. AGSE Summary

1.3.1. AGSE/Payload Title

ATLAS - Autonomous Terrestrial Launch Ascension System

1.3.2. Method for Autonomous Procedures

A BeagleBone Black (see ***Figure 1***) on the AGSE will control all autonomous procedures of the rocket and AGSE system. The BeagleBone will be connected to a system of sensors to track the progress of the AGSE and rocket through the various mission requirements. Between task completion signals, the BeagleBone will control a camera, robotic arm, stepper motor, and various servos to accomplish mission requirements.

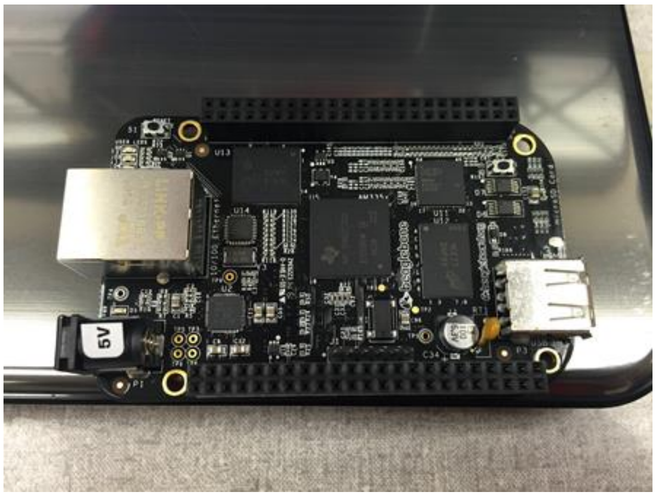


Figure 1 BeagleBone Black

Basic task sequencing will begin with the image processing system locating the sample. The imaging system and robotic arm will work together to retrieve the sample. After confirmation of sample retrieval is relayed to the BeagleBone, the arm will move the sample to the clamp on the rocket door. Inserting the sample into the clamp will compress a switch signaling the gripper to release the sample. The BeagleBone will then control the arm through closing the door. A switch on the door will tell the arm to move to a preset location away from the rocket. The BeagleBone will then power on and operate the stepper motor to raise the rocket to the desired launch position. At 5^{o} from vertical, a switch will allow the system to power on the stepper motor needed to insert the igniter. The igniter stepper motor will operate until a switch verifies it's in position. With the igniter inserted, the rocket can be verified for flight readiness by an official.

2. Changes Made Since Proposal

2.1. Vehicle Criteria

The nosecone will remain a blunt elliptical shape but have an overall length of 14 inches. This is a 4 inch reduction from the initially proposed length. Commercially bought elliptical nosecones are shorter than expected.

The fin geometry has been changed to improve the static margin based on a CG shift due to motor weight. The root chord has changed from 12 inches to 10 inches and the tip chord has changed from 5 inches to 4 inches.

The payload sample compartment design has been changed to a hinged door with a latching system instead of the sliding door. The kick panel clamps responsible for holding the payload will now be placed directly to the door. After the robotic arm has retrieved the sample, it will place the sample into the clamps and then perform a sweep maneuver to shut the door prior to vehicle erection. Two spring-loaded sliding locks will be mounted to the inside of the body tube. These will catch and lock two brackets that are mounted to the door when it falls shut. A foam mold in the shape of the sample will be placed where the clamps were previously located to help secure the sample during vehicle operation. Having a hinged door allows for a simple method to have the door be flush with the body tube once it is shut. This orientation would be difficult to achieve with a sliding door. Furthermore, it would be difficult to ensure that the sliding door would close under its own power. Having the arm close the door prevents the chance of the door not closing. The mold was added to ensure that the sample does not fall out of the clamps during flight.

2.2. AGSE/Payload Criteria

For time and complexity issues, the team has decided to purchase a robotic arm rather than construct one. The arm is an M100Rak V2 Modular Robotic Arm by RobotShop. It is a 4 degree of freedom modular robotic arm with a 500 gram lifting capacity at a full reach of 24 inches. The gearing is all metal with a 90 degree metal mount at the wrist for the gripper. The gripper (which adds an additional two degrees of freedom), servo controller, and power supply are all sold separately.

The igniter will now be inserted using a linear actuator system rather than the rollers discussed in the proposal. A threaded rod will spin via a stepper motor, pushing up a nut and thus the igniter attached to a wood dowel on top of the nut. Once the nut reaches the blast plate, the igniter will be fully inserted into the motor. This design prevents the change that the igniter will slip on the rollers and not be inserted. The linear actuator model also prevents the igniter from moving back down, eliminating the need for a cap and securing the igniter inside the motor.

2.3. Project Plan

The budget has been slightly adjusted from the proposal. For example, portions have been added to reflect items that have already been purchased (such as the robotic arm and servo controller). Because the arm came with the servos required to control it, the servos that were required to build an arm were removed. The budget also now reflects the parachutes being purchased, rather than being fabricated by the team. Despite these changes, however, the total budget accounted for thus far did not change by much ($10,005 from the proposal to $9,585). After the proposal was submitted, the Student Government Association agreed to fund the team with $1,000 for the spring semester of next year, and the full $7,000 was awarded from the NC Space Grant. The timeline has been updated to reflect the specifics on when the rocket and AGSE will be manufactured as well as the tentative dates for experimental verifications.

3. Vehicle Criteria

3.1. Selection, Design, and Verification of Vehicle

3.1.1. Mission Statement

The Tacho Lycos will design a launch vehicle to deliver a Mars soil sample to a 3000 foot AGL apogee and jettison the sample compartment at 1000 feet AGL on the decent to land safely back on the ground.

3.1.2. System Level Requirements

The following material was gathered from the NASA SL 2015 Handbook because of the comprehensive and complete description of requirements:

1.1. The vehicle shall deliver the payload to, but not exceeding, an apogee altitude of 3,000 feet above ground level (AGL).

1.2. The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude used in the competition scoring. The altitude score will account for 10% of the team's overall competition score. Teams will receive the maximum number of altitude points (3,000) by fully reaching the 3,000 feet AGL mark. For every foot of deviation above or below the target altitude, the team will lose 1 altitude point. The team's altitude points will be divided by 3,000 to determine the altitude score for the competition.

1.2.1. The official scoring altimeter shall report the official competition altitude via a series of beeps to be checked after the competition flight.

1.2.2. Teams may have additional altimeters to control vehicle electronics and payload experiment(s).

1.2.2.1. At the Launch Readiness Review, a NASA official will mark the altimeter that will be used for the official scoring.

1.2.2.2. At the launch field, a NASA official will obtain the altitude by listening to the audible beeps reported by the official competition, marked altimeter.

1.2.2.3. At the launch field, to aid in determination of the vehicle's apogee, all audible electronics, except for the official altitude-determining altimeter shall be capable of being turned off.

1.2.3. The following circumstances will warrant a score of zero for the altitude portion of the competition:

1.2.3.1. The official, marked altimeter is damaged and/or does not report an altitude via a series of beeps after the team's competition flight.

1.2.3.2. The team does not report to the NASA official designated to record the altitude with their official, marked altimeter on the day of the launch.

1.2.3.3. The altimeter reports an apogee altitude over 5,000 feet AGL.

1.2.3.4. The rocket is not flown at the competition launch site.

1.3. The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.

1.4. The launch vehicle shall have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.

1.5. The launch vehicle shall be limited to a single stage.

1.6. The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours, from the time the Federal Aviation Administration flight waiver opens.

1.7. The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.

1.8. The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system. The firing system will be provided by the NASA-designated Range Services Provider.

1.9. The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).

1.9.1. Final motor choices must be made by the Critical Design Review (CDR).

51.9.2. Any motor changes after CDR must be approved by the NASA Range Safety Officer (RSO), and will only be approved if the change is for the sole purpose of increasing the safety margin.

1.10. The total impulse provided by a launch vehicle shall not exceed 5,120 Newton-seconds (L-class).

1.11. Any team participating in Maxi-MAV will be required to provide an inert or replicated version of their motor matching in both size and weight to their launch day motor. This motor will be used during the LRR to ensure the igniter installer will work with the competition motor on launch day.

1.12. Pressure vessels on the vehicle shall be approved by the RSO and shall meet the following criteria:

1.12.1. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) shall be 4:1 with supporting design documentation included in all milestone reviews.

1.12.2. The low-cycle fatigue life shall be a minimum of 4:1.

1.12.3. Each pressure vessel shall include a solenoid pressure relief valve that sees the full pressure of the tank.

1.12.4. Full pedigree of the tank shall be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when.

1.13. All teams shall successfully launch and recover a subscale model of their full-scale rocket prior to CDR. The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale shall not be used as the subscale model.

1.14. All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on launch day. The purpose of the full-scale demonstration flight is to demonstrate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at a lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full scale demonstration flight:

1.14.1. The vehicle and recovery system shall have functioned as designed.

1.14.2. The payload does not have to be flown during the full-scale test flight. The following requirements still apply:

1.14.2.1. If the payload is not flown, mass simulators shall be used to simulate the payload mass.

1.14.2.2. The mass simulators shall be located in the same approximate location on the rocket as the missing payload mass.

1.14.2.3. If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems shall be active during the full-scale demonstration flight.

1.14.3. The full-scale motor does not have to be flown during the full-scale test flight. However, it is recommended that the full-scale motor be used to demonstrate full flight readiness and altitude verification. If the full-scale motor is not flown during the full-scale flight, it is desired that the motor simulate, as closely as possible, the predicted maximum velocity and maximum acceleration of the competition flight.

1.14.4. The vehicle shall be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the competition flight.

1.14.5. After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components shall not be modified without the concurrence of the NASA Range Safety Officer (RSO).

1.15. Each team will have a maximum budget they may spend on the rocket and the Autonomous Ground Support Equipment (AGSE). Teams who are participating in the Maxi-MAV competition are limited to a $10,000 budget while teams participating in Mini-MAV are limited to $5,000. The cost is for the competition rocket and AGSE as it sits on the pad, including all purchased components. The fair market value of all donated items or materials shall be included in the cost analysis. The following items may be omitted from the total cost of the vehicle:

• Shipping costs

• Team labor costs

1.16. Vehicle Prohibitions

1.16.1. The launch vehicle shall not utilize forward canards.

1.16.2. The launch vehicle shall not utilize forward firing motors.

1.16.3. The launch vehicle shall not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.).

1.16.4. The launch vehicle shall not utilize hybrid motors.

1.16.5. The launch vehicle shall not utilize a cluster of motors.

3.1.3. Subsystem Level Review

3.1.3.1. Nosecone

Model rocketry nosecones can be chosen for a wide range of flight conditions depending on speed and the mission. From preliminary design simulations, it was determined the rocket would operate well below supersonic and even transonic speeds with design specifications limiting the apogee to 3000' AGL. From this, it was determined this performance criteria would not require high aerodynamic efficiency.

An elliptical fiberglass nosecone was therefore chosen for use. The nosecone will be purchased from Rocketry Warehouse rather than manufacturing our own to save time and money. This nosecone has a 5.5" maximum diameter at the base with an exposed length of 8.5 inches and a shoulder length of 5.5 inches. The proposed design can be seen in ***Figure 2***.

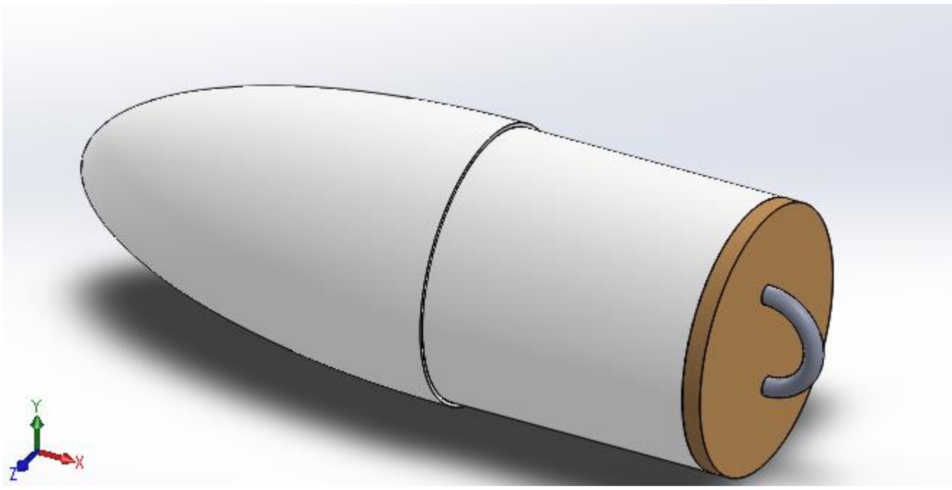


Figure 2 Nosecone Selection and Assembly

3.1.3.2. Airframe

The flight vehicle body tube will be constructed of 5.5 inch diameter Blue Tube 2.0. Blue Tube 2.0 offers greater strength than regular phenolic tubes while weighing less than fiberglass tubing. Designed for artillery illumination rounds, this material is highly resistant to abrasion and cracking making it unnecessary to add additional airframe reinforcements.

Internally, the body tube will be separated into four separate compartments with each section sealed by a bulkhead(s) constructed of 0.375 inch birch aircraft grade plywood. The fin section will contain a carbon fiber reinforced bulkhead for motor attachment and shock cord connection. This section will be secured to the middle airframe by inserting four nylon shear pins. This allows for the rocket to stay connected during pre-launch handling and still separate from a black powder charge at altitude. Internal to the fin section, two centering rings constructed of 0.375 inch birch aircraft plywood will be epoxied to ensure the motor is most nearly perfectly centered.

3.1.3.3. Avionics

Avionics will be implemented into both the upper and middle airframe. Each avionics compartment will include a set of primary and redundant Stratologger SL100 altimeters, two 9 V batteries, and a fiberglass sled to secure the components. The two independent sections will also contain GPS units for tracking purposes. The upper airframe avionics bay will be responsible for the drogue charge to deploy at the 3000 foot apogee, the

ARRD at 1100 feet, and the charge to separate the nosecone from the upper airframe at 1000 feet. This sled will also hold the payload mold to help secure the sample on the opposite side. The sled in the middle airframe will be responsible for the separation of the middle airframe and the fin section at 700 feet. Each altimeter will be wired to switches. This eliminates any unnecessary battery usage in the time of when the vehicle is not in launch configuration.

3.1.3.4. Stability

For the purposes of stability analysis, the datum reference point was established as the tip of the nosecone. From preliminary calculations in OpenRocket, the center of gravity was located 47.4 inches aft of datum and the center of pressure located 57.9 inches aft of datum. This makes for a static margin of 1.91 caliber as illustrated in ***Figure 3***.

Figure 3 Stability Visualization

One crucial stability based parameter is the vehicle's launch rail exit velocity. For sufficient stability off of the rail, Jim Livingston suggested a minimum velocity of 44 ft/s as the uppermost rail button leaves the launch rail. For the K535RR motor and a 66 inch launch rail, it was found that the vehicle's top rail button would leave the rail at 46 ft/s. The equation used to calculate this velocity is shown below. This equation is derived using the assumption that the forces acting on the vehicle as well as its mass are constant over the short time on the rail. In addition, rail friction was neglected as well as drag due to the low velocities being considered.

$$V_{rail\ exit} = \sqrt{\frac{2L(T - W\sin\theta)}{m}}$$

L is the distance the top rail button travels before it leaves the rail. This distance is related to the rail length by adding the distance between the top rail button and the base of the vehicle's fin section. T is the K535RR motor's average thrust over the first 0.25 s of flight, W and m are the vehicle's weight and mass respectively, and θ is the launch rail's angle from horizontal (specified from the launch requirements to be 85°). While this rail exit velocity is above the minimum value, drag, rail friction, non-constant thrust, and propellant burn-off were not taken into account. Also, the vehicle's weight is likely to increase between the preliminary design and final construction. This rail exit velocity will be verified using drag estimates from ANSYS's Fluent CFD program, propellant burn-off estimates, a final vehicle weight, and varying thrust values. The launch rail length will be adjusted if this more accurate rail exit velocity estimate does not meet the minimum value.

3.1.3.5. Fin Section

The fin section airframe will be a 22.5 inch section of 5.5" outer diameter Blue Tube. Four slots will be cut at 90 degree intervals that are 0.25" wide and 7" tall located 1.5" from the bottom surface of the airframe. A 5.34" diameter bulkhead will be epoxied 4" from the upper surface of the airframe. This bulkhead will secure a U-bolt responsible for connections between the fin section and middle airframe at main event separation. On the opposite side, a fiberglass tube 18" tall with a 2.13" diameter will be epoxied to act as the motor housing. Two centering rings constructed from birch aircraft plywood will be epoxied to the inner surface of the airframe to align the motor in the most axial direction possible. These centering rings will sit flush against the tabs extending from each of four fins to provide a more secure attachment of the fins and can be seen in Figure XX. Each fin will be constructed from birch aircraft grade plywood with a 0.25" thickness. Fin dimensions can be seen in ***Figure 5***.

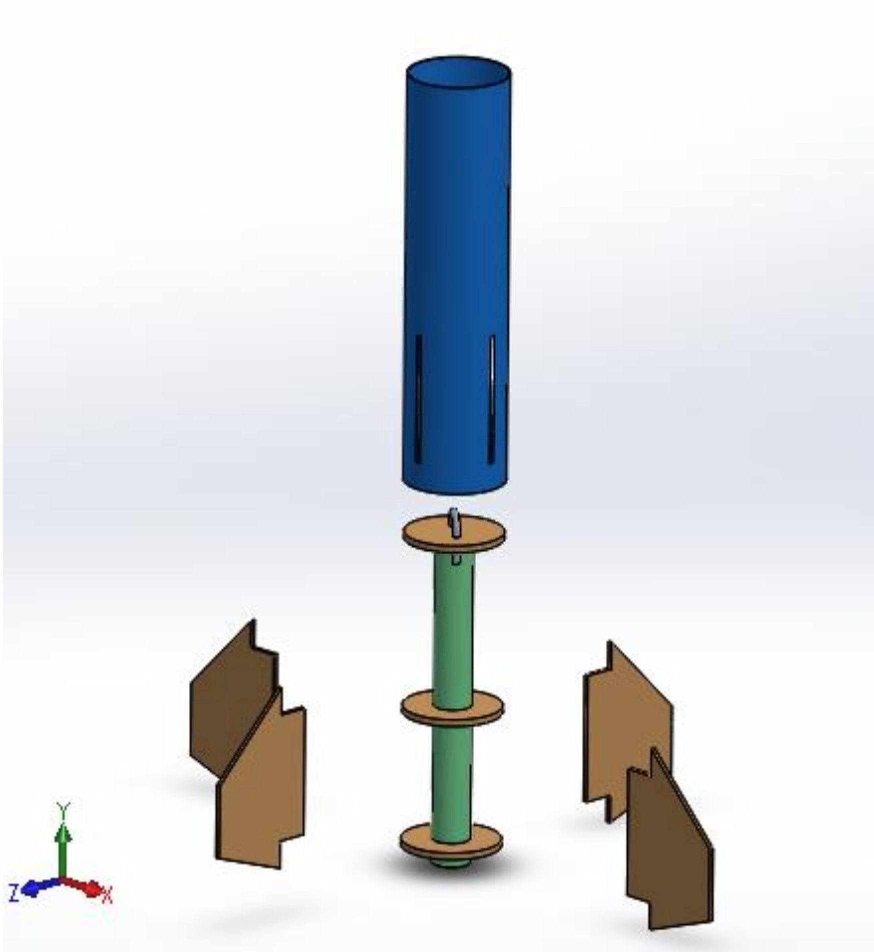


Figure 4 Fin Section Exploded View

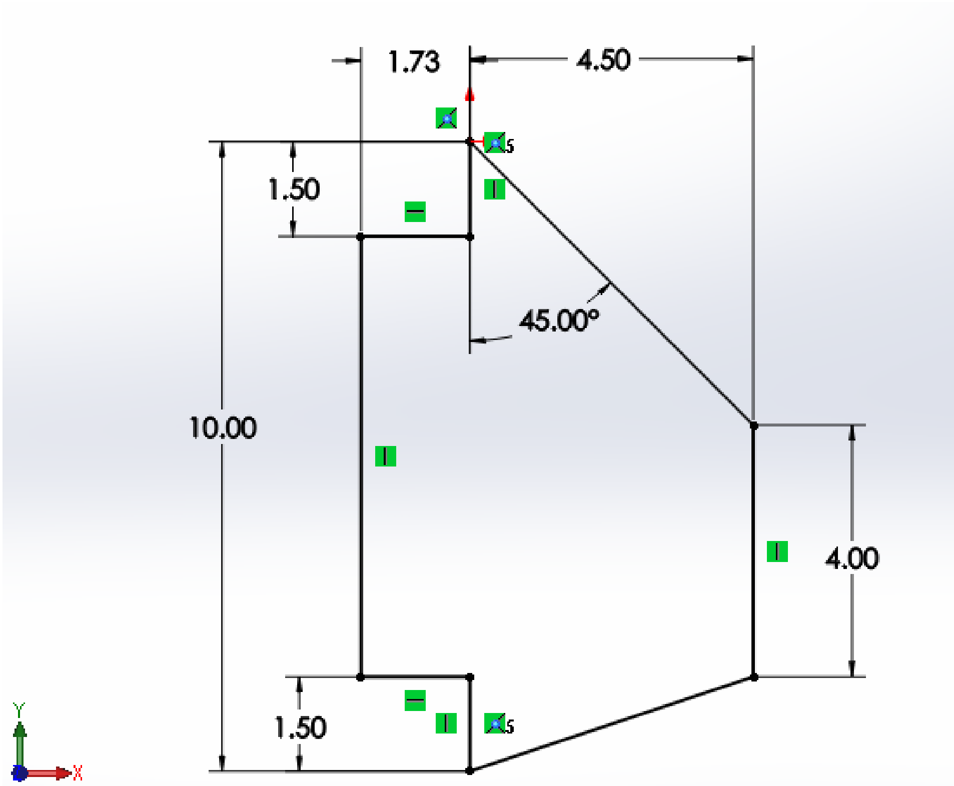


Figure 5 Fin Geometric Dimensions (inches)

3.1.3.6. Motor

The Animal Motor Works K535RR motor was chosen in order to give the launch vehicle the ability to reach the target altitude, while giving a stable rail exit velocity, and fitting within the motor requirements. The motor has an overall length of 15.9 inches, and a diameter of 2.13 inches. The total impulse is given as 324 lbf-s. The propellant weight that will be burned off in the first 2.7 seconds of the launch will be 1.68 lbs. When the motor has combusted the stability margin will increase to 3.1 calibers. Using Open Rocket simulations, this motor shows an apogee of 3,270 feet. While this is over the requirement of 3,000 feet, the team believes there will be added weight during the build process that is not yet accounted for in the initial calculations. Excess resin, extra sensors, and increases in parachute sizing could cause the weight could fluctuate from the current predictions by a small amount. If the weight does not fluctuate as expected, small pieces of mass can be added to the nose of the rocket to bring the apogee closer to the required 3,000 feet.

3.1.3.7. Payload Compartment

The payload compartment door will be hinged to the body tube such that the door rotates about the axial direction of the rocket. Each hinge will be attached to the flat, bottom section of a mount with a top that is contoured to the 5.34" inner diameter body tube. Prior to autonomous activation, the door will be placed in an open orientation. The inside of the compartment door will have a Quik Klip 420 Series 0.75" diameter mount from BRIM Electronics, Inc. mounted to it for payload sample containment as illustrated in ***Figure 6***.

Figure 6 Quik Klip Payload Retention Device

The autonomous procedure will have the arm grapple the sample and place it into the Quik Klip as shown in ***Figure 7***.

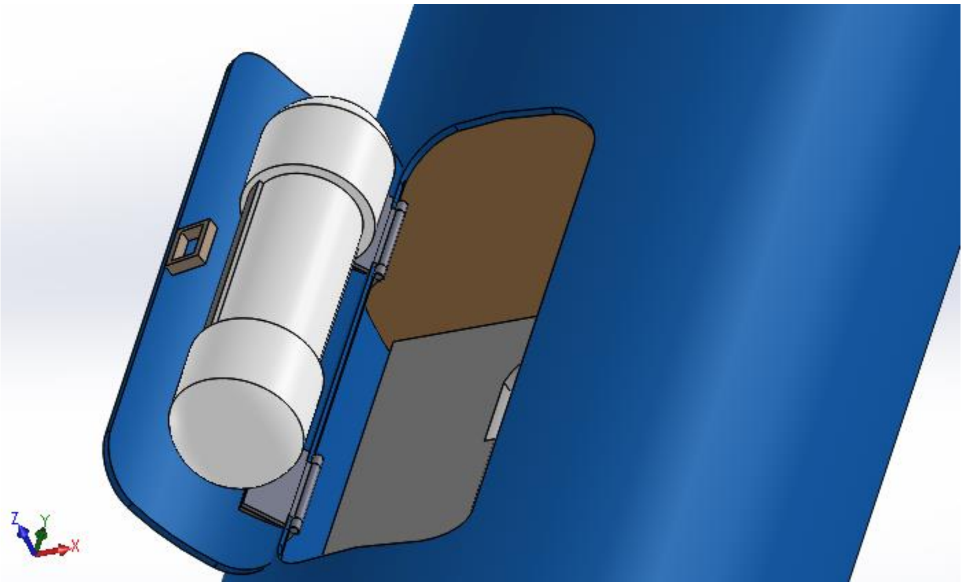


Figure 7 Secured Payload Orientation

The arm will then perform a sweep maneuver to flip the door to the closed position. A McMaster-Carr spring-loaded sliding lock will be mounted to the inside of the body tube that will act as the locking mechanism of the door. At the center of the door, the square bracket will be mounted. When the door falls shut, the bracket will compress the spring lock until they are able to extend and lock into the bracket's center. When the section is disassembled, the knob pull will be accessible from inside the compartment allowing the lock to release and the door to open. A mold with a cutout in the shape of the payload sample will be placed inside the payload compartment. The mold will made from foam and act as a saddle for the sample to rest in when the door is in the closed position. This will ensure that the sample stays in its designated position even if the grip from the Quik Kip fails. This mold will be mounted to the avionics sled on the side opposite of the altimeters and batteries. This configuration is illustrated in ***Figure 8***and ***Figure 9***.

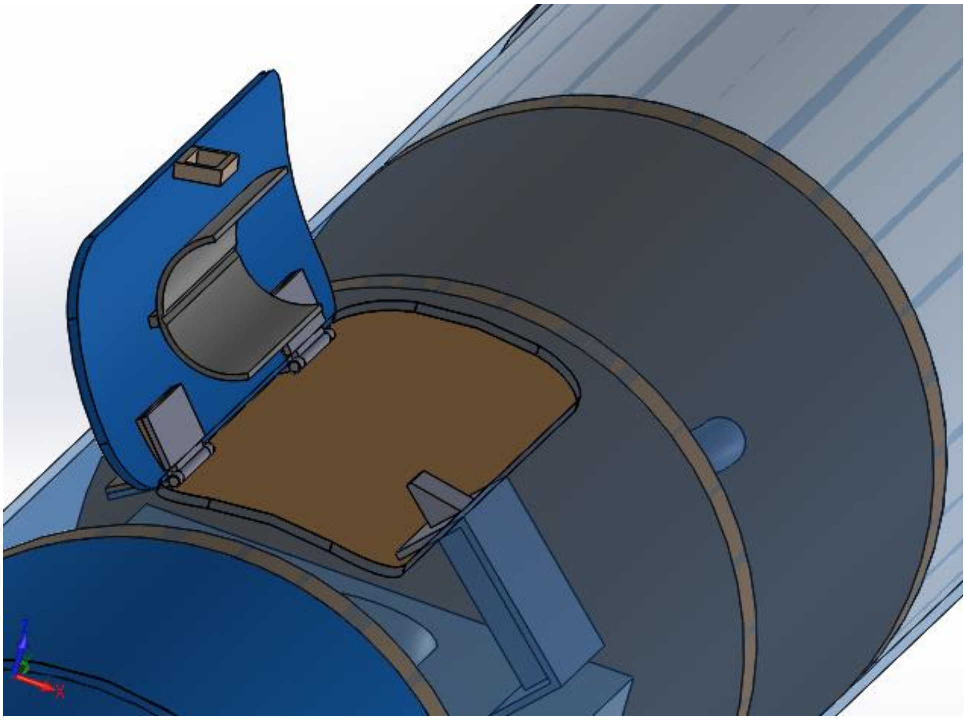


Figure 8 Door Latch System Visualization

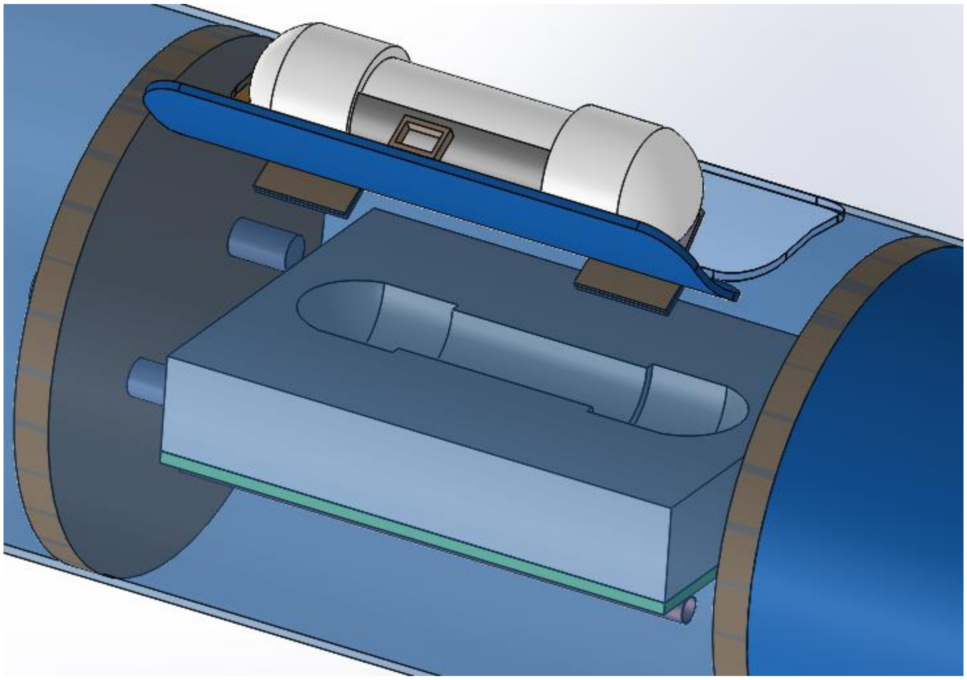


Figure 9 Sample Mold Visualization

3.1.4. Performance Characteristics for System and Subsystem

The systems and subsystems will be deemed successful if they carry out their respective tasks. Ideally, the tasks will only take one attempt to accomplish. The system will still be successful though if it can fully convey its potential, even if it takes more than one attempt. The level of accuracy will be measured by how close the systems come to the expected results, such as when the parachutes deploy to release the sample section. Many of the tasks are crucial to the success of the entire mission, just as picking up the sample and retaining it within the rocket. Systems such as these will be evaluated on a pass/fail basis.

3.1.5. Verification Plan

At this time, the major vehicle requirements, their corresponding design features, and methods for requirement verification have been determined. The verification criteria for implicit and team dictated requirements is still being developed. A summary of the major vehicle requirements and their verification methods are shown in ***Table 1***. In addition, this section includes detailed information about planned ARRD and altimeter testing.

Table 1 Summary of Vehicle Verification Plan

Requirement	Satisfying Design Feature (s)	Verification
3,000 ft Apogee	Airframe Dimensions, Mass, Motor	OpenRocket Analysis

1,000 ft Payload Separation	ARRD, Altimeters	Experimental Ejection Testing
Vehicle Recovery/Reusability	Altimeters, Parachutes, Shock Cord	Ejection Testing, Inspection
Successful Payload Retention	Compartment Door, Quik-Klamps, Sample Mold	Experimental/Simulated Functional Analysis
Vehicle Stability	Weight Distribution, Fin Geometry, Launch Rail Exit Velocity	OpenRocket, Barrowman Method, and Fluid Simulation Analyses
Electronic Section Tracking	GPS Modules, Radio Transmitter	Testing, Inspection

ARRD Testing:

The ARRD (shown below in ***Figure 10***) is a crucial aspect of the recovery system. To ensure a separation of the middle and upper airframes by the ARRD charge, multiple tests will be conducted to measure the necessary amount of black powder for separation. Tests will be performed by mounting the device in a secure and static position with a weight that is attached and suspended from the ARRD's eye bolt with a specified amount of black powder inserted to the explosive cavity. The weight will be equivalent to the expected forces encountered at parachute deployment. Charge sizes will start at 0.1 g black powder and increased in step sizes of 0.1 g for subsequent tests. The success criteria will be determined by the minimal amount of black powder necessary to cause separation of the eye-bolt from the ARRD.

Figure 10 Advanced Retention Release Device

Altimeter Testing:

The purpose of this experiment is to verify that both the StratoLogger SL100 altimeters will function properly. The altimeters must be able to fire the drogue and main black powder charges as well as record pressure data to function properly. A 5 gallon bucket will be fashioned into a vacuum chamber that will be used to test the altimeters at different pressures. A hole will be cut into the lid where tubing will be inserted and sealed with a rubber cap. This tubing will be connected to a compressed air vacuum attachment illustrated in ***Figure 11***. An additional cutout will be made to the bucket's lid and covered with a piece of Plexiglas that is sealed by plumbers putty. This will allow for visual confirmation of LEDs that will be attached to the altimeter and emit light when the simulated drogue and main pressure altitudes are encountered. This setup is illustrated in ***Figure 12***. A vacuum pressure of 4 inHg will slowly be applied with the assumption of roughly 1000' per 1 inHg. A laptop will then be connected to each altimeter to collect and interpret data which will verify the altimeters performance.

Figure 11 Altimeter Test Vacuum Attachment

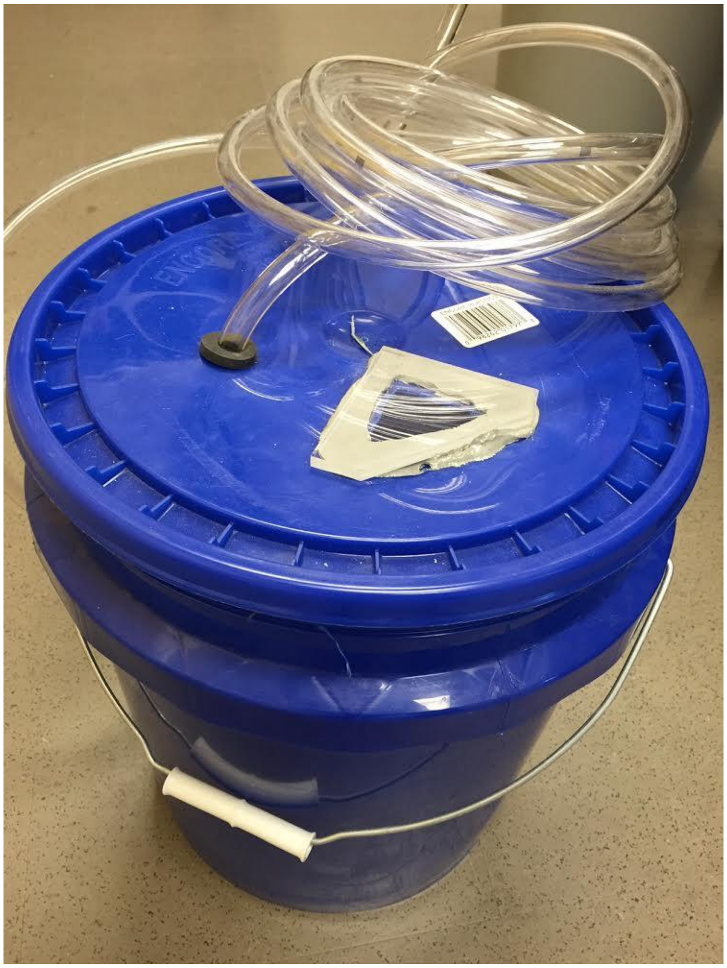


Figure 12 Altimeter Test Vacuum Compartment

3.1.6. Project Risks

Risk	Likelihood	Impact	Mitigation	Mitigation Cost
Overspending	Low	Medium	Proper Budgeting	May have to pull money from other systems
Delays	Medium	High	Proper Planning and Diligence	May have to sacrifice time from other areas, causing delays
Lack of Resources	Low	High	Thorough Bill of Materials	Sacrificing items from other areas

Improper Design	Medium	High	Proper Analysis of Each Subsystem	May Attempt to Spend Too Much Time on a Single System
Rocket Motor Failure	Low	High	Use Well-Established Motor	May Need to Purchase a More Expensive Rocket
Can't Identify Sample	High	High	Fully Test the Imaging System or Purchase Better Camera	Different Camera May Increase the Cost of the AGSE
Sample Falls out of Retainer	Medium	Low	Increase Retainers in Rocket	Increase in Weight of Rocket
Motors Fail	Medium	High	Use Larger Motors	Increase in Weight and Price
Insufficient Power Supply	Medium	High	Use Larger Power Supply	Increase in Weight and Price

3.1.7. Understanding of Project Components

All of the risks defined in the ***Appendix 2***(the FMECA diagrams) must be taken into account when designing the vehicle and AGSE. Accounting for these risks will ensure the safety of the team. Any of the safety risks coming to fruition would severely impact progress on the design, or halt the work completely. As with any project, there is also the risk of going over budget. This risk should be avoided, and can be if proper care is taken to keep up with team's capital. If the team goes over budget, then at the very least points will be lost or the team may be disqualified overall. Lastly, ample time must be allotted to each section of the design, documentation included. Any delays would quickly compound and push back progress on other aspects of the design, potentially preventing the project to be finished. Therefore, it is imperative that the team remain on schedule whenever possible.

3.1.8. Planning of Manufacturing, Verification, Integration, and Operations

The NCSU High Power Rocketry Club is located in the MAE Student Fabrication Lab, Room 2003, Engineering Building III. The club members also have access to the Space and Aircraft Senior Design Labs in Rooms 1224 and 1225.

In addition to the design labs, the club will have access to two machine shops on the first floor of Engineering Building 3. Gary Lofton is the supervisor for the machine shop located in Room 1205 and gladly helps with design and parts requests. The MAE department machine shop is in Room

1228 and is controlled by Steve Cameron. The structures lab in Room 2208 will provide additional resources including the Instron tensile and compression loading machine for materials testing.

Available equipment in room 2003 consists of the following:

- Craftsman 1.6 inch Variable Speed Scroll Saw
- Craftsman 12 inch Bench Drill Press (***Figure 13***)
- Task Force 4" Belt & 6" Disc Sander (***Figure 14***)
- 120 Volt 60 Hz Band Saw (***Figure 15***)
- 16 Gallon 6.5 HP Shop Vac
- Dremel 400 XPR Rotary Tools
- Ryobi HG600 Heat Gun
- Drill Bit Case from 3/64" – ½" inch
- Task Force Ratchet/Socket Kit
- Digital Micrometer
- SoftWorks 5lb Food Scale
- AWS 1 kg Digital Scale
- Wilton Bench Vice
- Vacuum hoses for wet layups

Figure 13 Drill Press

Figure 14 Task Force Belt and Disc Sander

Figure 15 Band Saw

Bulkheads will be constructed using epoxy and a vacuum seal. A large, clean surface that is free of any debris will be covered with a plastic lining that is sized to accommodate the amount of bulkheads needed. The size of the lining will be such that the desired amount of bulkheads take up half of the sheets size. This is so the lining can be folded in half over itself. Prior to placing the lining, thin strips of plumbers putty will be placed along the entire outer perimeter of the lining. The bulkheads will then have the epoxy applied and the carbon fiber reinforcements positioned. The bulkheads will be carefully placed on the lining and sheets of peel ply will be cut to cover each bulkhead with approximately two inches of overhang along the entire edge. Breather will then be cut to the same size as the peel ply and placed directly over the peel ply. Strips of breather will be bridged from bulkhead to bulkhead all the way to the location of the vacuum tubing. This will ensure no air pockets remain trapped and an even pressure is applied at all points. Plumbers putty will then be placed adjacent to and along the entire previous putty lining on the inside edge, except for a one inch gap at the open end of the plastic lining fold. The vacuum tubing will then be inserted in this location and additional putty will be applied around the tubing to keep an airtight seal. The vacuum will then be applied to a pressure of -20 inHg for 8-12 hours minimum.

The fins will also be constructed from a combination of birch aircraft plywood and carbon fiber in an effort to keep weight low. We chose carbon fiber over a fiberglass laminate to increase strength and decrease weight. The fins will be created in the exact same process as the bulkheads using the combination of West Systems epoxy and vacuum application. If the combined production amount of bulkheads and fins can be accommodated into one layup, both will be created at the same time. The fins will pass through the outer body tube and will be attached to the motor mount inner tube with epoxy. On the outside of the vehicle body the fins will have a tip to tip layer of carbon fiber or fiberglass to reduce any warping of the fins which could cause a constant roll during flight. Due to shape complexity of the fin section, the layup will mainly air dry with partial heat gun application if needed.

3.1.9. Confidence and Maturity of Design

The team is confident that the vehicle design will work, given previous experience with rocket design and construction. Although the image processing subsystem is a bold task, the team believes that it can get the process to work and successfully identify and retrieve the sample. The team also believes that the overall launch system is driven by completely feasible design features.

3.1.10. Assembly Drawing

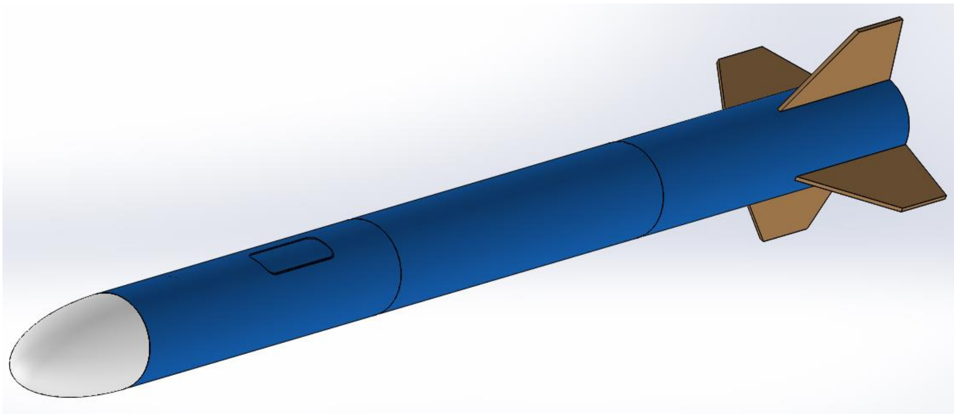


Figure 16 Full Scale Flight Configuration

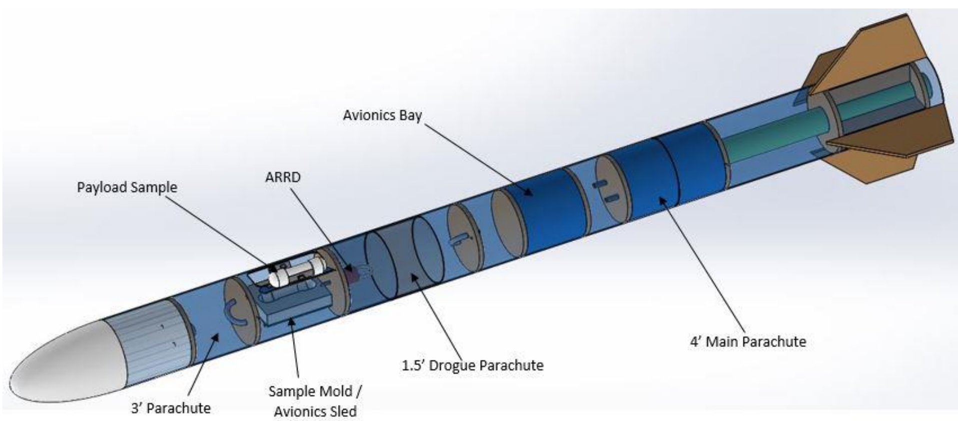


Figure 17 Full Scale Subsystems Visualization

3.1.11. Recovery System Electrical Schematics

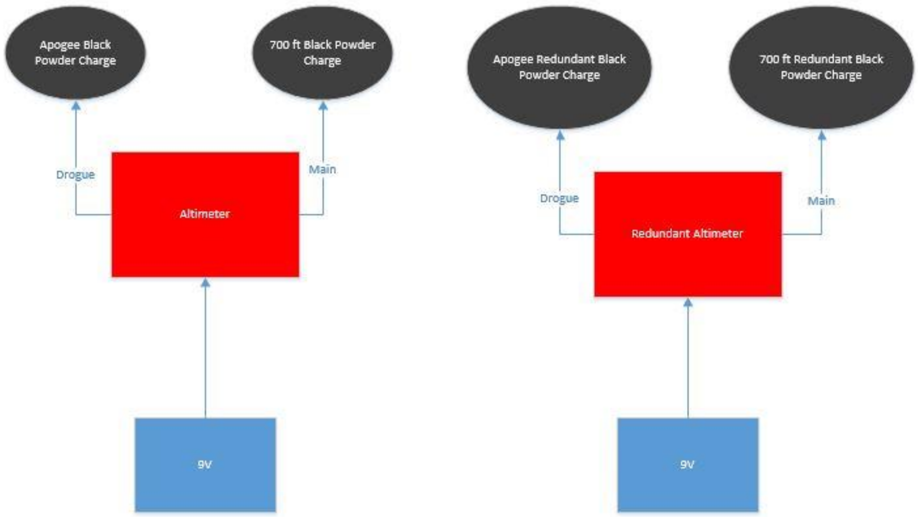


Figure 18 Fin Section Recovery Schematic

Figure 18 above shows the electrical schematic for the fin section of the vehicle. The avionics in this section will consist of two altimeters, one as the primary and the other for redundancy. Each altimeter is hooked up to a 9V power supply and two black powder charges. The first black powder charge, set to deploy the drogue parachute, is hooked up to the drogue port on the altimeter. The second charge is set to go off at 700 feet to deploy the main parachute for this section and is hooked up to the main parachute port on the altimeter. As shown the diagram, the redundant altimeter has the same setup, but slightly larger black powder charges.

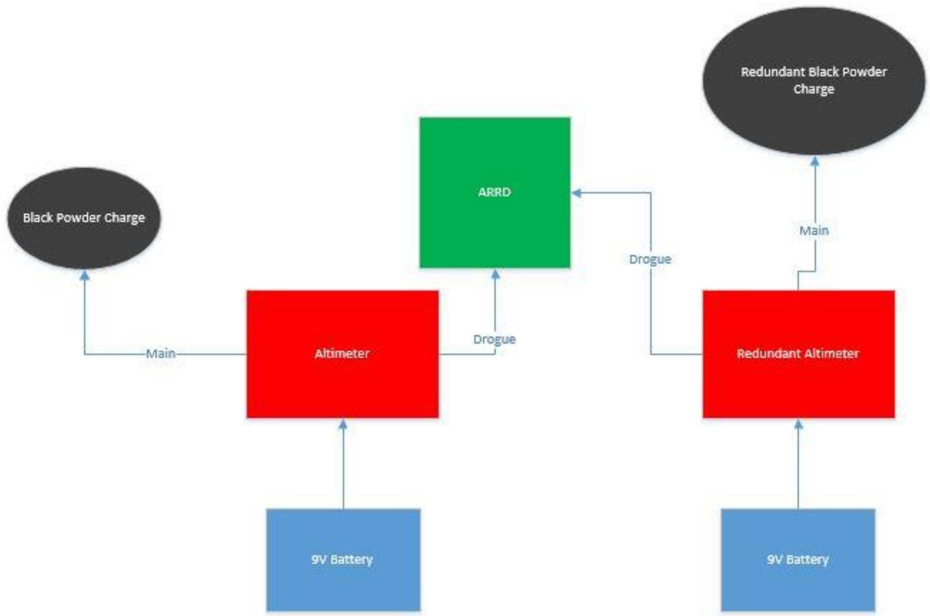


Figure 19 Nosecone Recovery Schematic

As shown in ***Figure 19***, the nosecone section has a similar setup to the fin section. Two altimeters are used, with one being used for redundancy, and are both hooked up to 9V power supplies. The main altimeter has its main parachute port hooked up to a black powder charge, set to go off at 1000 feet. The backup altimeter has the same setup, but with a slightly larger black powder charge set to go off at 900 feet. Furthermore, each altimeter has its drogue port hooked up to the ARRD, which is set to go off at 1100 feet.

3.1.12. Mass Statement

The rocket is currently estimated to weigh 15.25 pounds. The weight of the rocket is based on the weights OpenRocket from Solidworks. Therefore, the weights obtained are quite accurate. Part of this weight includes the weight of the motor (3.43 lb) and the weight of the parachutes and harnesses (2 lb). Because this weight does not include the additional epoxy and paint that will be needed to build the rocket, the team is expecting a weight increase of about 15% of the total weight. This weight should not interfere with the rocket, although the rocket currently comes off of the launch rail very close to the minimum velocity required for stability. This small margin can be counteracted, however, by increasing the length of the launch rail.

3.2. Recovery Subsystem

The recovery system utilizes three parachutes, four altimeters, black powder charges, and an Advanced Retention Release Device (AARD). At apogee, a 1.5 foot drogue parachute will deploy. This will separate the middle airframe and fin section from the upper airframe and nosecone.

The drogue will be attached to the ARRD in the upper airframe and to a bulkhead in the middle airframe. This event is illustrated in ***Figure 20***.

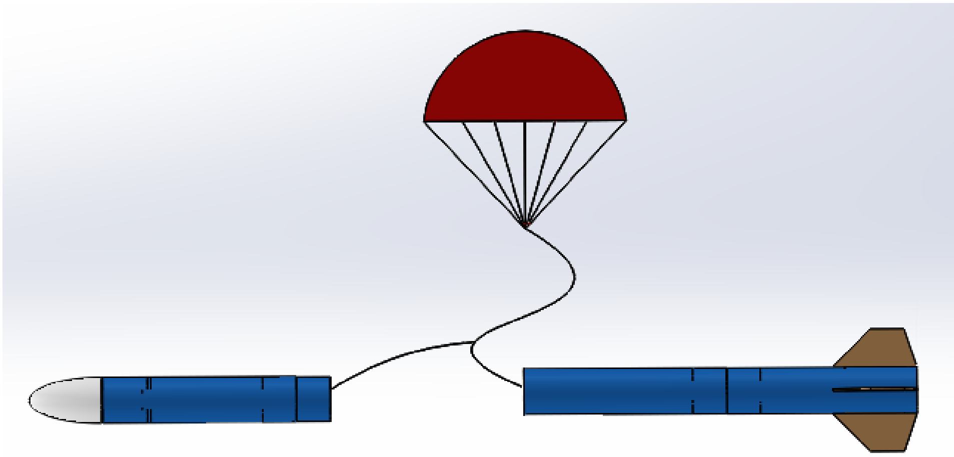


Figure 20 Drogue Parachute Deployment (Apogee)

At 1100 feet, the ARRD will separate the nose cone and upper airframe from the middle airframe and fin section. Shortly after, at 1000 feet, the sample section and nose cone will separate, releasing a 2.75 foot main parachute. This is event is illustrated in ***Figure 21***.

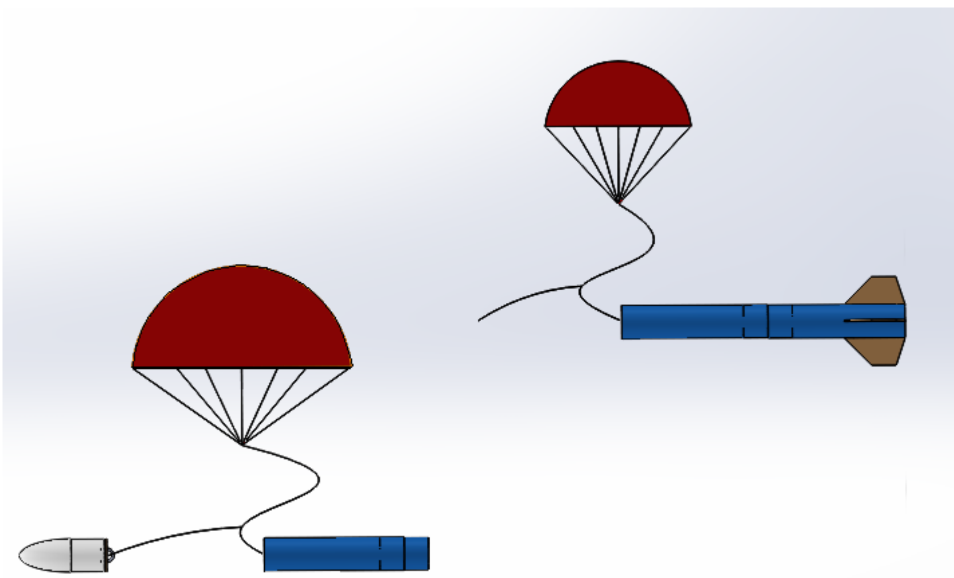


Figure 21 Sample Compartment Separation/Parachute Deployment (1100/1000 ft)

In order to decrease the drift range, a 3.75 foot main parachute will deploy at 700 feet between the middle airframe and fin section. This event is illustrated in ***Figure 22***.

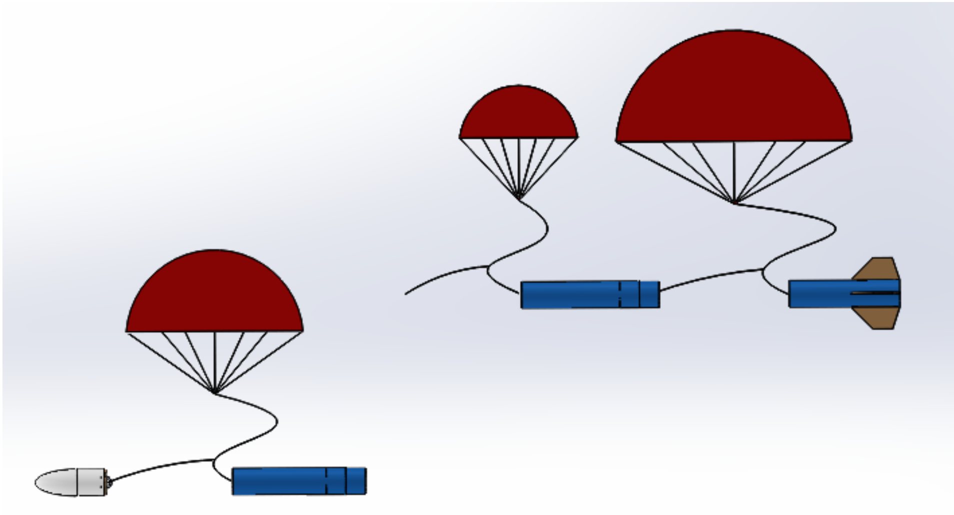


Figure 22 Fin Section Main Parachute Deployment (700 ft)

3.3. Mission Performance Predictions

3.3.1. Mission Performance Criteria

As stated in the Request for Proposal, the vehicle needs to reach as close to the 3000 foot mark as a possible. Therefore, this is the first criterion that the vehicle must reach. At apogee, a drogue parachute will deploy, followed by the separation of this drogue at 1100 feet and the release of a main parachute attached to the sample container and nosecone. Another main parachute will then deploy at 700 feet, as described in detail above. Each section of the rocket must also come down with a maximum kinetic energy of 75 ft-lb. In order for the vehicle to perform correctly and as planned, all of the criteria above must be met. Achieving these criteria will result in a successful performance of the vehicle.

3.3.2. Flight Profile Simulations

Figure 23 below shows a flight profile simulation from OpenRocket using the Animal Motor Works K535RR motor with the drogue parachute deploying at apogee plus 1 second, the nosecone main parachute deploying at 1000 feet, and the fin section main parachute deploying at 700 feet.

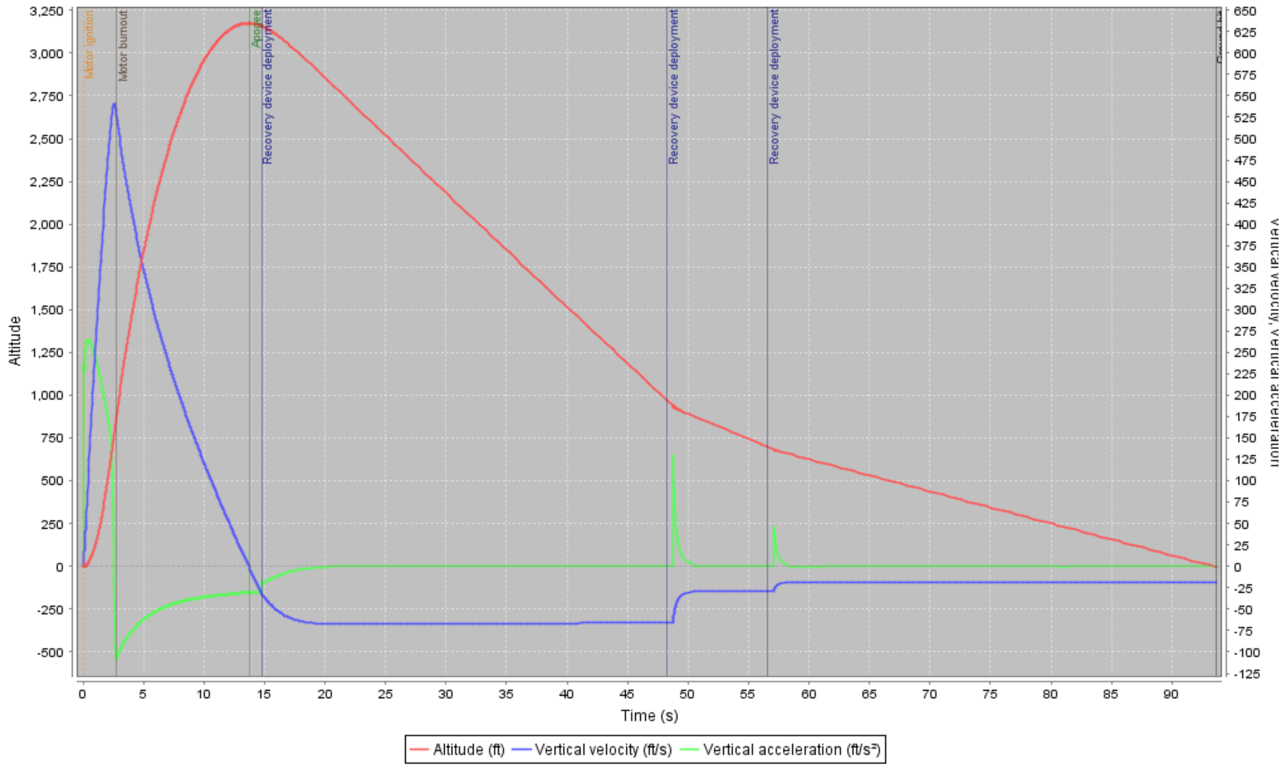


Figure 23 OpenRocket Flight Profile

The thrust curve in pound force for the Cesaroni K535RR can be seen in ***Figure 24*** below.

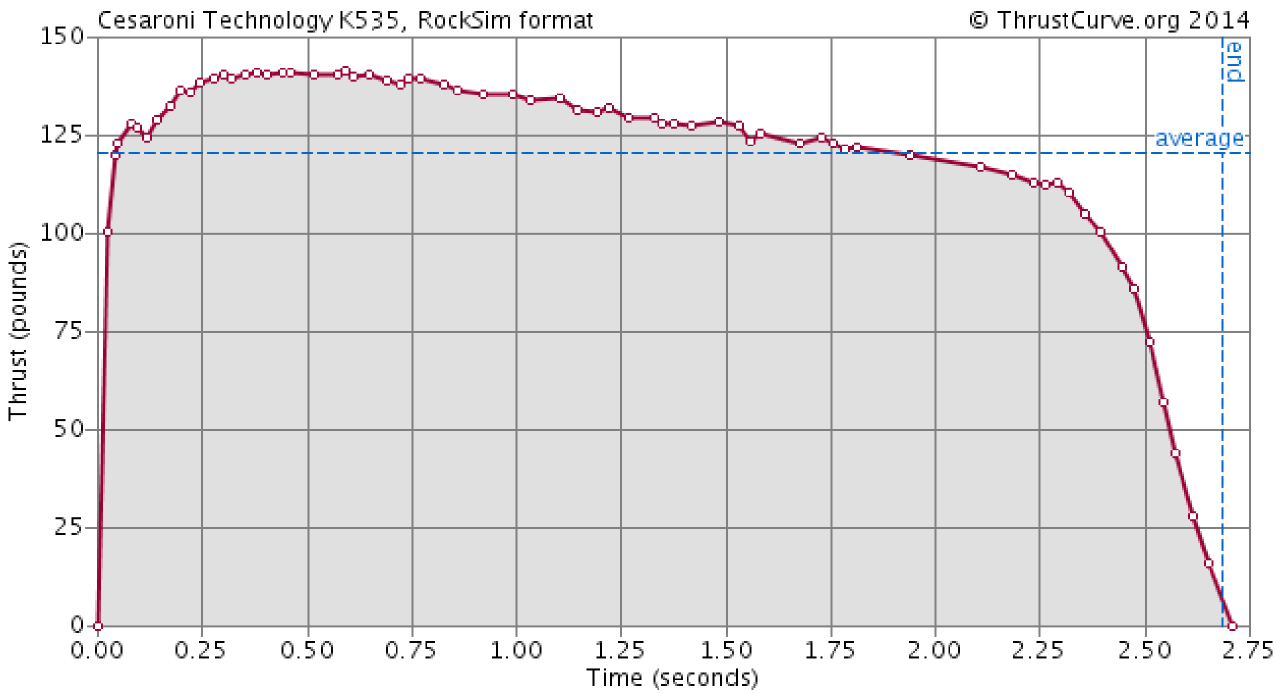


Figure 24 Thrust Curve for Cesaroni K535RR Motor

3.3.3. Stability Margin, CP, CG

OpenRocket and Barrowman's equations were both used to find the stability margin, CP, and CG of the vehicle. OpenRocket gave a static margin of 1.9, with the center of gravity located 47.4 inches aft of the datum, and the center of pressure located 57.9 inches aft of the datum. In comparison, Barrowman's equations gave values of 1.61 for the static margin and 56.24 inches aft of the datum for the location of the center of pressure, using the same center of gravity location noted above. Barrowman's Method was done assuming the center of pressure of the elliptical nosecone was located one half of the nosecone's length. This value is the same as for a parabolic nosecone, and was used because the parabolic nosecone closely models the elliptical nosecone. These values will be re-examined once a more accurate value for an elliptical nosecone can be obtained.

3.3.4. Kinetic Energy at Landing

A MATLAB program was written to determine the parachute sizes required to keep the velocity and kinetic energy to acceptable levels. The MATLAB program assumed the drag coefficient of the parachutes to be 1.75. The density was assumed to be standard sea level and was set at 0.002377 slugs/ft^3. The velocity was calculated using the equation:

$$V = \sqrt{\frac{2D}{C_D \rho A}}$$

Where D equals the weight of the vehicle, C_D equals the drag coefficient, rho represents the density, and A gives the area of the parachute. The kinetic energy KE was found using:

$$KE = 0.5mV^2$$

Where m is the mass of the rocket, and V is the velocity found above. These results were then plotted against different parachute sizes to determine the ideal size required to keep the vehicle reusable.

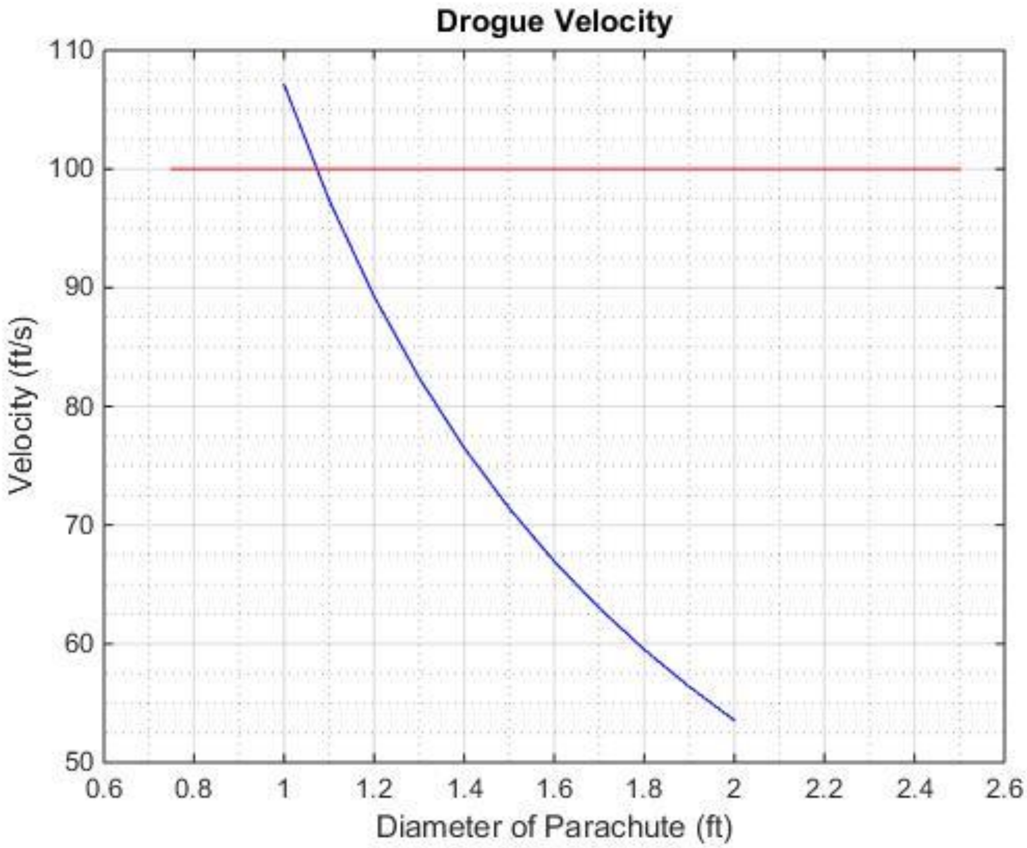


Figure 25 Vehicle under Drogue Velocity

Under the club's mentor's guidance, 100 ft/s was chosen as the maximum velocity the vehicle will fall under drogue. Using that requirement, a 1.5 foot drogue parachute was chosen to deploy at apogee. ***Figure 25*** above shows the parachute diameters required to slow the parachute down to 72 ft/s. The rocket weight, after propellant burn, was used to calculate these values.

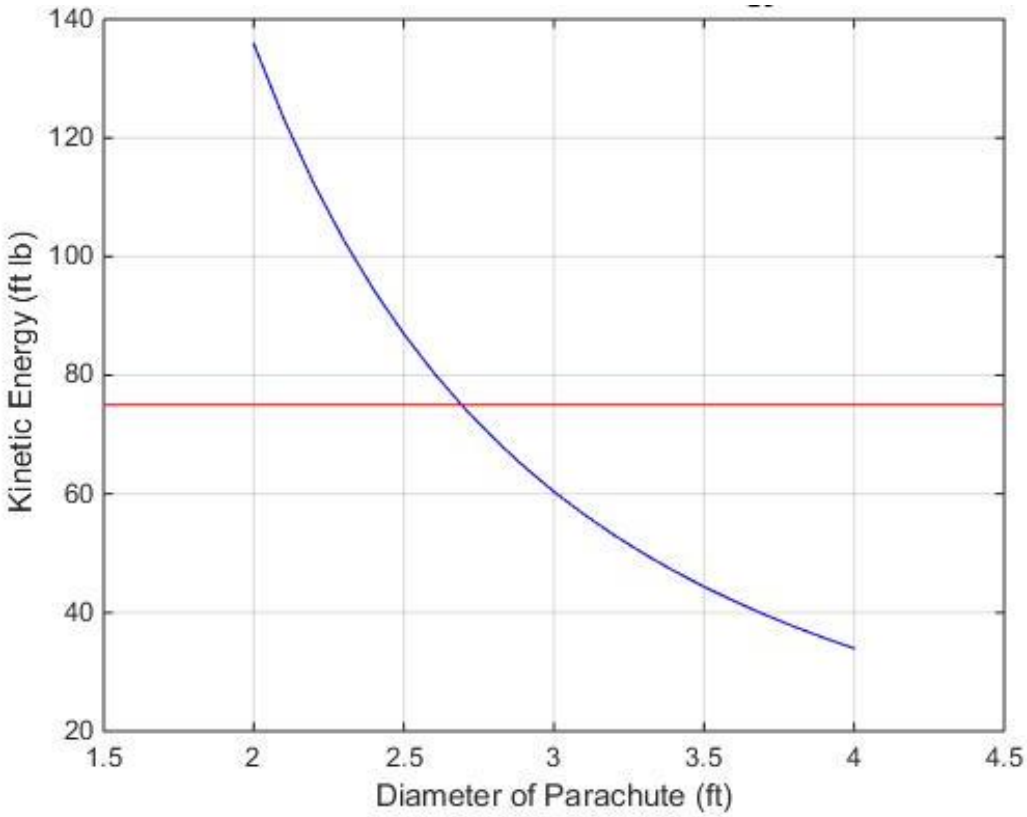


Figure 26 Main Nosecone Kinetic Energy Calculator

At 1000 feet, the main parachute will deploy from the nosecone and payload section of the vehicle. This section must hit the ground with a kinetic energy of below 75 ft lbs. In order to accomplish this a 3 foot main parachute was chosen, as shown in ***Figure 26*** above. This will slow the nosecone down to 21 ft/s. The rocket weight, after propellant burn, was used to calculate these values.

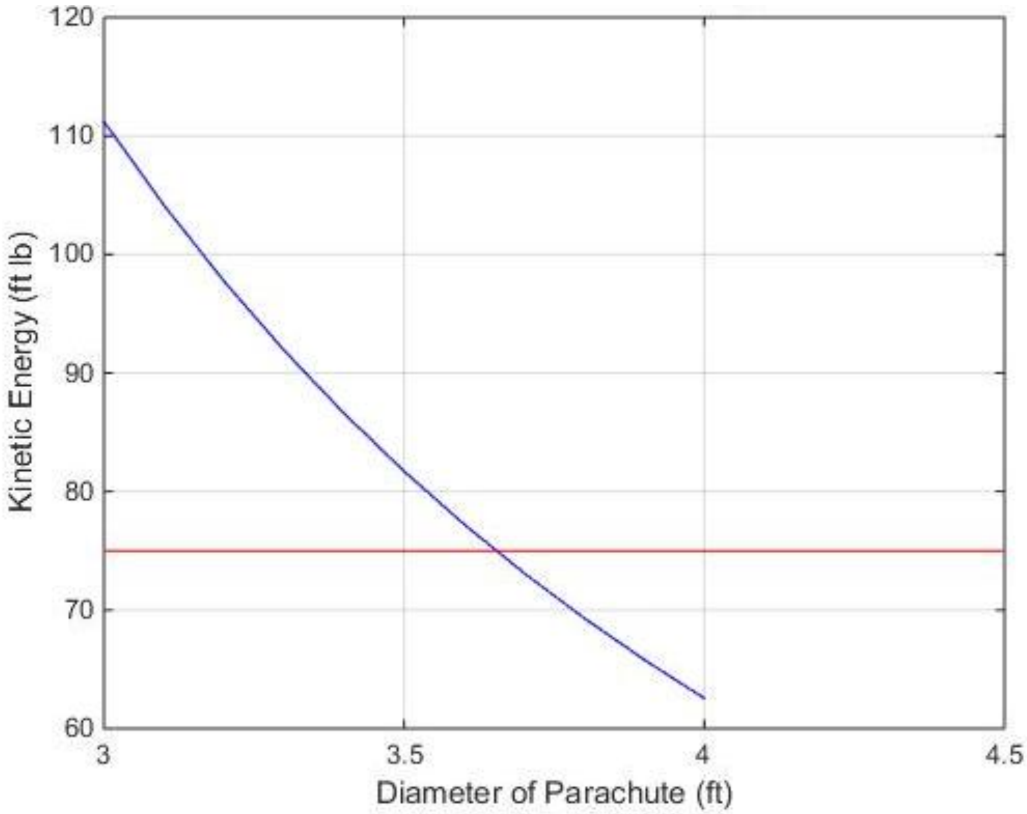


Figure 27 Main Fin Section Kinetic Energy Calculator

Once the fin section reaches 700 feet the main parachute will come out of that section. This section also has the requirement to land with less than 75 ft-lbs of kinetic energy. Using ***Figure 27*** above, a 4 foot diameter parachute was chosen to allow the fin section to also land safely to allow for reusability. This parachute will slow the fin section down to 24 ft/s. The rocket weight, after propellant burn, was used to calculate these values.

3.3.5. Wind Drift

A MATLAB code was written in order to determine the maximum drift distances at different wind speeds. The distances were calculated separately for the nose cone and fin sections of the rocket. The maximum drift was calculated for varying atmospheric conditions in order to be able to determine adjustments necessary to control the descent of the different sections of the rocket.

The total time spent airborne for each section was calculated by dividing the terminal velocities by the distances in each stage of the decent. The first stage of the descent took place before the sections separated and was described by a constant velocity of 72 ft/s from an altitude of 3000 ft to 1000 ft. The second stage for the fin section was described by a constant velocity of 72 ft/s from an altitude of 1000 ft to 700. From 700 ft to the ground, the fin section maintained a velocity of 21 ft/s. The second and final stage for the nose cone took place from 1000 ft to the ground at a constant velocity of

24 ft/s. The total time spent airborne was 65 seconds and 69 seconds for the fin section and nose cone, respectively.

Once the total times were calculated for each section, two separate loops were implemented to calculate the drift distances for wind speeds of 5, 10, 15, and 20 mph. Since the previous calculations represented ft/s, the wind speeds were converted by multiplying by 22/15, resulting in speeds of 7, 15, 22, and 29 ft/s. The maximum drift distances can be seen in ***Table 2*** below with a corresponding visual of the distances in ***Figure 28***.

Table 2 Wind Drift Predictions

Wind (mph)	Payload Section (ft)	Fin Section (ft)
0 (blue)	0	0
5 (green)	510	480
10 (brown)	1020	960
15 (yellow)	1530	1440
20 (red)	2040	1915

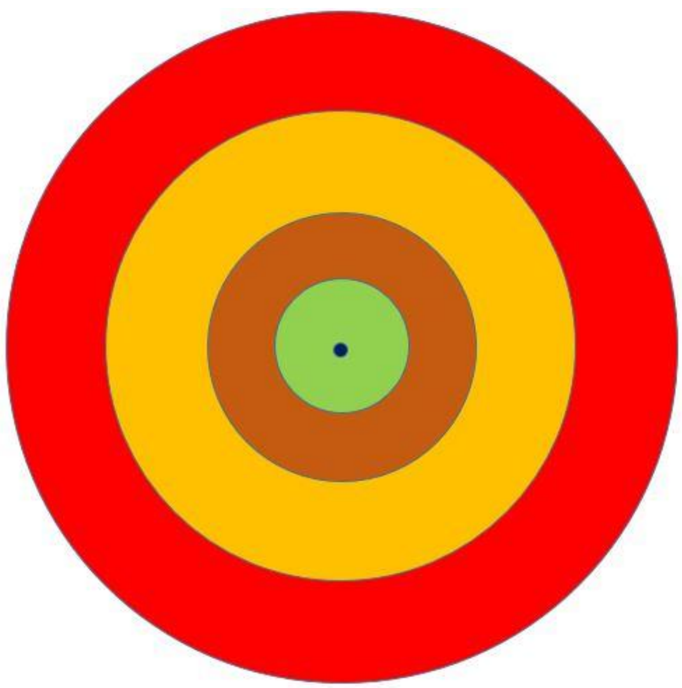


Figure 28 Wind Drift Diagram

3.4. Interfaces and Integration

3.4.1. Payload

The payload will be identified on the ground with a USB camera and an image processing system on the BeagleBone. The camera will be mounted on the hand of the robotic arm and will take images incrementally as the hand moves closer to the sample. The image processing system will find the distance from the camera to the sample and relay that information to the control the robotic arm.

After the location of the sample has been identified with the imaging system, a BeagleBone will search for the x-y-z coordinates outputted by the imaging system in a table of coordinates and servo inputs required to move to those locations. In order to allow for greater accuracy, the arm will only move a portion of the distance to the sample to allow for another picture to be taken. It is expected that 4 pictures will be needed at most to correctly identify the location of the sample. The 2-pincer gripper on the arm will then grab the sample in the center, perpendicular to its length. Once the gripper has a hold of the sample, the arm will then move to a preset location to insert the sample into its container. The arm will then be used to close the hatch door and secure the sample inside of the rocket. In order to cope with the side forces on the sample, the Quik Klips will prevent the sample from moving laterally within the vehicle. They will also aid in preventing the sample from moving up and down. The mold for the sample (that also doubles as a sled for the avionics), will prevent the sample from falling out of the Quik Klips and moving around inside the rocket.

3.4.2. Internal Compartments and Subsystems

The forward payload houses the forward avionics section. This section has two altimeters and a GPS unit attached to the back of the sled that holds the payload. This section is encompassed by two bulkheads. The rear avionics bay also houses two altimeters and a GPS unit to track the fin section after separation. There are 0.25 inch aircraft plywood bulkheads separating all the section that hold either avionics or a parachute. The motor section has it reinforced bulkhead that acts as a motor block to protect the vehicle from any failures that may occur during the propellant burn time.

3.4.3. Launch Vehicle and Ground Station Interfaces

The Digi XBee-Pro XSC GPS transmitter will be used to relay GPS location data for the two separate vehicle sections to the ground station. Integration between the RSO's procedure pause switch and the launch system will be discussed in the AGSE electrical schematics section.

3.4.4. Launch Vehicle and AGSE Interfaces

In addition to being mounted to the AGSE launch rail, the launch vehicle will interact electronically with the AGSE's BeagleBone. There will be a total of two switches mounted on the rocket's sample compartment door. The first, mounted near the Quik-Klip, will verify when the sample has been successfully inserted. The second will verify that the sample door is closed.

3.5. Safety

3.5.1. Launch Operation Procedures

To ensure all hazards and accidents are avoided, the NCSU HPRC will follow the published Tripoli Pre-Flight Review Checklist:

a. General

- i. Is this member known to the TAP reviewer?
- ii. Does this member have the appropriate Certification Level or will this be a Certification Flight?
- iii. Does the proposed launch site and date have the appropriate recovery area and launch set-up for this flight?
- iv. Does the Prefect require TAP Review?

b. Rocket Review

- i. General
  1. Are there attachments to the Pre-Flight Data Capture?
  2. Drawings: airframe; structures; payloads, etc.
  3. Schematics: avionics, ignition systems, payloads, etc.
  4. Performance calculations: Center of Pressure; Center of Gravity, motor type, altitude, velocity, etc.
- ii. Airframe
  1. Is the design generally suitable for the application?
  2. Is the airframe material suitable for this rocket?
  3. Is the fin material/attachment sound?
  4. Is the motor mount sound?
  5. Is the nosecone suitable?
  6. What are the most probable airframe faults and corrective actions?
  7. What are the safety implications of an airframe failure?
  8. Are there any design change recommendations?
- iii. Recovery System
  1. Is the recovery system attachment secure/suitable?
  2. Does the recovery system have sufficient capacity for a safe descent?
  3. What is the deployment system?
  4. What are the most probable deployment system faults and corrective actions?
  5. What are the safety implications of a recovery system failure?
  6. Are there any design change recommendations?
- iv. Avionics Description
  1. Commercial or unique design?
  2. What are the functions of the avionics components?
  3. Are the avionics appropriate to the application?
  4. Do the avionics have flight safety implications?
  5. Can the avionics and inhibits be accessible from outside the vehicle?

6. Are there safeing/arming indicators?
7. Are any of the systems redundant?
8. What are the most probable avionics system faults and corrective actions?
9. What are the safety implications of an avionics system failure?
10. Are there any design change recommendations?

v. Motor

1. Is the motor suitable for the rocket?
2. Is the motor Tripoli Certified?
3. Is the motor ignition suitable?
4. What are the most probable motor faults and corrective actions?
5. What are the safety implications of a motor failure?
6. Are there any design change recommendations?

vi. Launcher

1. Is the launcher suitable for the rocket?
2. Is the launch lug, or rail guide suitable for the rocket?
3. What will the launch angle be?
4. Are there any special launch control requirements?
5. What are the most probable faults with the launcher?
6. What are the safety implications of a launcher failure?
7. Are there any design change recommendations?

vii. Performance

1. How were the performance calculations done?
2. Were the calculations done manually?
3. Are the algorithms used correct?
4. Were the calculations accomplished correctly?
5. Was a computer used?
6. What is the source of the software?
7. Is the software suitable for this rocket?
8. Are there printouts?
9. Should the calculations be independently run?
10. What are the safety implications of poor performance data?
11. Are there any changes or recommendations?

viii. Operations

1. Is there a pre-flight checklist?
2. Which operations does it cover?
3. Are each the operations sufficiently documented?
4. Are hazardous operations flagged?
5. What are the safety implications of poor checklists?
6. Are there any changes or recommendations?

b. AGSE Review

i. General

1. Are there attachments to the Pre-Flight Data Capture?
2. Drawings: structures; payloads, etc.
3. Schematics: electronics, payloads, etc.
4. Performance calculations: Center of Gravity, motor type, etc.

ii. AGSE Structure

1. Is the design generally suitable for the application?
2. Is the material suitable for this rocket?
3. Is the leg material/attachment sound?
4. Are the Servo mounts sound?
5. What are the most probable frame faults and corrective actions?
6. What are the safety implications of a frame failure?
7. Are there any design change recommendations?

iii. Electronics Description

1. Commercial or unique design?
2. What are the functions of the electronics components?
3. Are the electronics appropriate to the application?
4. Can the electronics and inhibits be accessible from outside the vehicle?
5. Are there safeing/arming indicators?
6. Are any of the systems redundant?
7. What are the most probable electronics system faults and corrective actions?
8. What are the safety implications of an electronics system failure?
9. Are there any design change recommendations?

v. Servo

1. Is the Servo suitable for the AGSE?
2. Is the Servo Tripoli Certified?
3. Is the Servo ignition suitable?
4. What are the most probable Servo faults and corrective actions?
5. What are the safety implications of a Servo failure?
6. Are there any design change recommendations?

vi. Performance

1. How were the performance calculations done?
2. Were the calculations done manually?
3. Are the algorithms used correct?
4. Were the calculations accomplished correctly?
5. Was a computer used?
6. What is the source of the software?
7. Is the software suitable for this rocket?
8. Are there printouts?
9. Should the calculations be independently run?
10. What are the safety implications of poor performance data?
11. Are there any changes or recommendations?

vii. Operations

1. Is there a pre-flight checklist?
2. Which operations does it cover?
3. Are each the operations sufficiently documented?
4. Are hazardous operations flagged?
5. What are the safety implications of poor checklists?
6. Are there any changes or recommendations?

3.5.2. Safety Officer

Jamie Region

Jamie Region will act as the safety officer for the North Carolina State University 2014-2015 NASA Student Launch team. Jamie has been an active High Power Rocketry Club member since 2012 and has sufficient experience in all aspects of rocketry safety. When present, she will oversee all activities conducted in the student fabrication lab as well as at the launch site. When Jamie is unavailable, the responsibilities will be fulfilled by the highest ranking club officer present.

The active safety officer will provide the proper safety measures to all NCSU High Power Rocketry Club members and accompanying guests, the working environment, any construction, testing, and vehicle launches.

3.5.3. Failure Mode Effects and Criticality Analysis

The FEMECA Diagram Spreadsheet is located in ***Appendix 2.***

NAR Environmental Regulations

The NAR High Power Rocket Safety Code document addresses the following environmental regulations:

Flight Safety. I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site. 2

Launch Site. I will launch my rocket outdoors, in an open area where trees, power lines, buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater.

Launcher Location. My launcher will be 1500 feet from any inhabited building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.

Recovery System. I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.

Recovery Safety. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

4. AGSE Criteria

4.1. Selection, Design, and Verification of Vehicle

4.1.1. System Level Requirements

The following material was gathered from the NASA SL 2015 Handbook because of the comprehensive and complete description of requirements:

4.1.1. The Maxi-MAV will provide each team with the opportunity to develop a unique method to capture, contain, launch, and eject a payload with limited human intervention. In addition, teams will develop a launch system that erects a rocket from a horizontal to vertical position, and has its igniter autonomously installed. On launch day, each launch will follow this general procedure.

4.1.1.1. Teams will position their launch vehicle horizontally on the AGSE.

4.1.1.2. A master switch will be activated to power on all autonomous procedures and subroutines.

4.1.1.3. After the master switch is turned on, a pause switch will be activated, temporarily halting all AGSE procedure and subroutines. This will allow the other teams at the pads to set up, and do the same.

4.1.1.4. After setup, one judge, one launch services official, and one member of the team will remain at the pad. The rest of the team must evacuate the area. The one team member is only there to answer questions the launch services official may have, and is not permitted to interact with the AGSE in any way.

4.1.1.5. After all nonessential personnel have evacuated, the pause switch will be deactivated.

4.1.1.6. Once the pause switch is deactivated, the AGSE will progress through all subroutines starting with the capture and containment of the payload, then erection of the launch platform, and lastly the insertion of the motor igniter. The launch platform must be erected to an angle of 5 degrees off vertical pointed away from the spectators. The launch services official may re-enable the pause switch at any time at his/her discretion. If the pause switch is re-enabled all systems and actions shall cease immediately. The launch services official will only do this if there is an obvious safety hazard. The judge, launch services official, and team leader will meet to discuss and decide if the team will be allowed to do a reset and rerun of their attempt. No modifications to the hardware will be allowed prior to a rerun.

4.1.1.7. The one team member will arm all recovery electronics.

4.1.1.8. Once the launch services official has inspected the launch vehicle and declares that the system is eligible for launch, he/she will activate a master arming switch to enable ignition procedures.

4.1.1.9. All personnel at the launch pad will evacuate the area.

4.1.1.10. The Launch Control Officer (LCO) will activate a hard switch, and then provide a 5-second countdown.

4.1.1.11. At the end of the countdown, the LCO will push the final launch button to initiate launch.

4.1.1.12. The rocket will launch as designed and jettison the payload at 1,000 feet AGL during descent.

4.1.2. The Autonomous Ground Support Equipment (AGSE)

4.1.2.1. For the purpose of this challenge, ASGE is defined as all mechanical and electrical components not part of the launch vehicle, and is provided by the teams. This includes, but is not limited to, the payload containment and igniter installation devices, computers, electric motors, batteries, etc.

4.1.2.2. All AGSE systems shall be fully autonomous. The only human interaction will be when the launch services official pauses or arms any equipment, when the team arms the recovery electronics, and when the LCO initiates launch.

4.1.2.3. Any pressure vessel used in the AGSE will follow all regulations set by requirement 1.12 in the Vehicle Requirements section.

4.1.3. Payload

4.1.3.1. Each launch vehicle must have the space to contain a cylindrical payload approximately 3/4 inch in diameter and 4.75 inches in length. The payload will be made of ¾ x 3 inch PVC tubing filled with sand and weighing approximately 4 oz., and capped with domed PVC end caps. Each launch vehicle must be able to seal the payload containment area autonomously prior to launch.

4.1.3. 2. Teams may construct their own payload according to the above specifications, however, each team will be required to use a regulation payload provided to them on launch day.

4.1.3. 3. The payload will not contain any hooks or other means to grab it. A diagram of the payload and a sample payload will be provided to each team at time of acceptance into the competition.

4.1.3. 4. The payload may be placed anywhere in the launch area for insertion, as long as it is outside the mold line of the launch vehicle when placed in the horizontal position on the AGSE.

4.1.3. 5. The payload container must utilize a parachute for recovery and contain a GPS or radio locator.

4.1.3. 6. Each team will be given 10 minutes to autonomously capture, place, and seal the payload within their rocket, and erect the rocket to a vertical launch position five degrees off vertical. Insertion of igniter and activation for launch are also included in this time. Going over time will result in the team's disqualification from the Maxi-MAV competition.

4.1.4. Safety and AGSE Control

4.1.4.1. Each team must provide the following switches and indicators for their AGSE to be used by the LCO/RSO.

4.1.4.1.1. A master switch to power all parts of the AGSE. The switch must be easily accessible and hardwired to the AGSE.

4.1.4.1.2. A pause switch to temporarily terminate all actions performed by AGSE. The switch must be easily accessible and hardwired to the AGSE.

4.1.4.1.3. A safety light that indicates that the AGSE power is turned on. The light must be amber/orange in color. It will flash at a frequency of 1 Hz when the AGSE is powered on, and will be solid in color when the AGSE is paused while power is still supplied.

4.1.4.1.4. An all systems go light to verify all systems have passed safety verifications and the rocket system is ready to launch.

4.1.2. AGSE Subsystems

Due to the complexity of fabricating a robotic arm, a RobotShop M100RAK V2 Modular Robotic Arm Kit is in the process of being purchased. A depiction of the arm can be seen below in ***Figure 29***. The arm itself provides 4 degrees of freedom, and the additional gripper to be added to the arm adds an additional 2 degrees. Therefore, in all, the arm will have 6 degrees of freedom. The claw to be used is a Lynxmotion Little Grip Kit (which comes with 2 HS-422 servos) purchased from RobotShop. As shown in ***Figure 30***, will have a two-prong pincer design that can both rotate around the wrist and pinch closed to grab the sample. According to the manufacturer's specifications, the arm has a total of 252 degrees of possible rotation at each joint, and the gripper can rotate 180 degrees about its axis. Furthermore, the gripper can open to 1.3 inches, allowing it to fit around the diameter of the sample. The 5:1 gears that it utilizes increases the torque output by a factor of 5, allowing the arm to lift more weight at its maximum reach (about 24 inches, not including the additional reach with the gripper). At its maximum length, the arm is capable of lifting about 500 grams, more than enough to support itself, the 4 oz (113 g) sample, and 13 g camera.

Figure 29 AGSE Robotic Arm

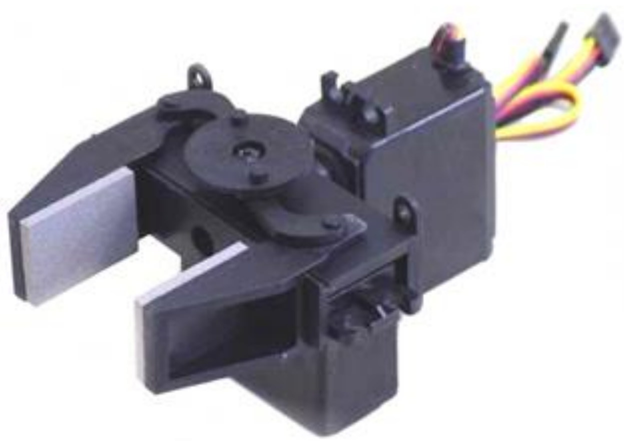


Figure 30 Gripper Used on the Arm

In order to get the arm to the sample, a table has been made that contains various x-y-z coordinates in space and the respective servo inputs needed to reach that location in space. This table was made using forward kinematics by inputting the angles that each portion of the arm would need to move, and then calculating the location of the end of the arm in space. The x and z coordinates of the end of the arm are given by:

$$X = l_1 \cos(\theta_1) + l_2 \cos(\theta_1 + \theta_2)$$

$$Z = l_1 \sin(\theta_1) + l_2 \sin(\theta_1 + \theta_2)$$

Where X is the x-coordinate of the end of the arm (the x-direction is taken to be along the horizontal, in the direction of the arm), Z is the z-coordinate of the end of the arm (taken to be the vertical), l_1 is the length of the arm from the shoulder to the elbow (9.6 inches), l_2 is the distance between the elbow and the wrist (12.75 in), Θ_1 is the angle between the shoulder and the horizontal, and Θ_2 is the angle of the forearm measured with respect to the axis of the bicep. When the arm spins around its base, the Y coordinate of the end of the arm is the y-coordinate of the circle the arm sweeps out. Because the radius of the circle is the X coordinate of the end of the arm, the Y coordinate is given by the equation

$$Y = Xsin(\theta_3)$$

Where Y is the y-coordinate of the end of the arm and Θ_3 is the angle of rotation of the base. All angles are taken to be positive counterclockwise. ***Figure 31*** below contains all of the points in space the arm is capable of reaching, assuming the full 252 degrees of freedom at each joint. A mesh spacing of 0.5 radians (about 30 degrees) was used in making ***Figure 31*** so that the individual points can be seen. The actual table used for the competition will have a much finer spacing (on the order of 0.01 rad). Furthermore, an example orientation of the arm is shown below in ***Figure 32***. Having a 3D plot of the arm makes it easier to view how the arm looks at each of the servo angles in the table.

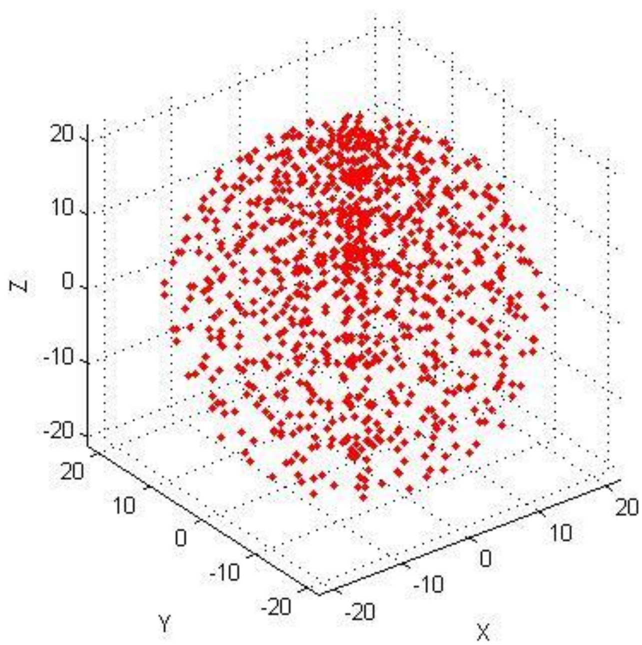


Figure 31 Robotic Arm Range if Unimpeded (inches)

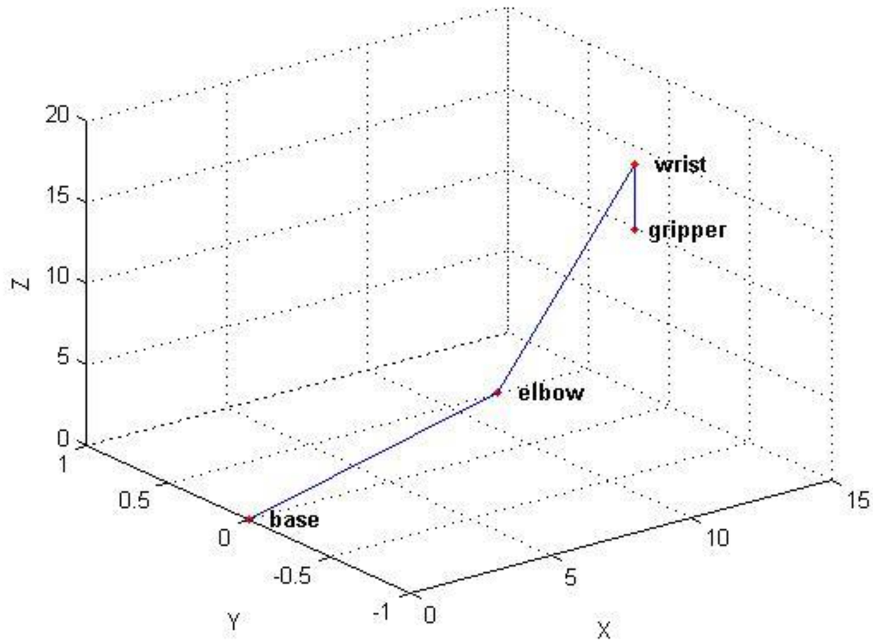


Figure 32 Example Orientation of the Arm Plotted with MATLAB Code

According to the given specifications of the servos, a 600 µs pulse corresponds to a full stop counter-clockwise rotation and a 2400 µs pulse corresponds to a full stop clockwise rotation. Therefore, the neutral position of the servos is at 1500 µs. For simplicity, this servo angle will make the arm fully extended along the x-axis. Given these specifications, and the fact that a 1 degree rotation of the arm corresponds to a 5 degree rotation of the servo, the required pulse widths needed to move the arm to a certain location in space can be calculated and tabulated as described above.

This system is to be implemented in the overall AGSE by having the imaging system identify the x-y-z location of the pipe in space. Then, the BeagleBone Black will look up these values in the table, interpolating as necessary, to find the corresponding servo inputs needed to move the arm to that location. As of now, this interpolation is to be done by subtracting the x-y-z location of the pipe from the corresponding values of each row in the table. These differences are then summed, and the minimum is found to identify the table entry that is closest to the desired coordinates. Assuming there is a small enough step size in the table, this method should allow the arm to get close to the sample without having to calculate the servo inputs every time. Current testing with a BeagleBone Black shows that it takes the program about 30 seconds to do a simple calculation on a 70000x3 table. In order to cut down on the computation time, only the needed angles for the arm will be tabulated. Since we know the location of the sample ahead of time, the program will only account for the angles around the general location the sample will be. Using this method will cut down on the information that needs to be stored, but prevent having to hard code the location of the sample into the program. Furthermore, the table will be broken down into smaller tables so that the xyz coordinates can be sorted before the program searches through the table. By only using angles necessary and pre-sorting the table, the computation time can be cut down. Once the sample has been secured inside the gripper of the arm, the arm will move to a preset location so that the sample can be inserted into the c-clamps. The arm will then be used to push the hatch door closed before the rocket is erected.

Launch Rail Lifting System

The vehicle's launch rail will be raised using a gear-driven system. This system, shown in ***Figure 33***, will consist of a sector-shaped gear fixed to rotate with the launch rail, a smaller intermeshing gear, and a planetary gearbox stepper motor (shown in ***Figure 34***). The sector-shaped gear will have an angle of approximately 120 degrees and a radius of 10 in. The smaller, intermeshing gear has a radius of 1 in and will be driven by the geared stepper motor. Details for the stepper motor are included in ***Table 3*** below. The stepper motor was chosen over a regular electric motor for its ability to rotate discrete angular steps. For a pre-determined number of pulses, the stepper motor can be commanded to rotate the sector-shaped gear and launch rail the desired 85 degrees.

To determine the required stepper motor holding torque, the moments created by the rocket and launch rail weights about the launch rail hinge were summed. The weight of the rocket was overestimated to be 30 lb to account for a possible increase in vehicle weight, unforeseen changes to the launch rail, and to allow future rockets to use this launch rail. Dividing the resulting moment by the gear ratio (10:1) yielded a required holding torque of 12 ft-lb. The maximum holding torque of the chosen planetary gearbox stepper motor is 29.5 ft-lb. This yields a safety factor of 2.5. For the required 85 degree angular rotation of the launch rail and the given gear ratios, it was determined that the stepper motor would need to undergo about 110 rotations (~22,000 steps). The stepper motor will be commanded by the BeagleBone Black through the stepper motor driver.

While the stepper motor is raising the launch rail, a ratcheting brace between the launch rail and AGSE base will provide secondary support in case of loss of power to the stepper motor. When the launch rail reaches 85 degrees to the horizontal, a pin will engage in the side of the sector gear to lock it in place for launch.

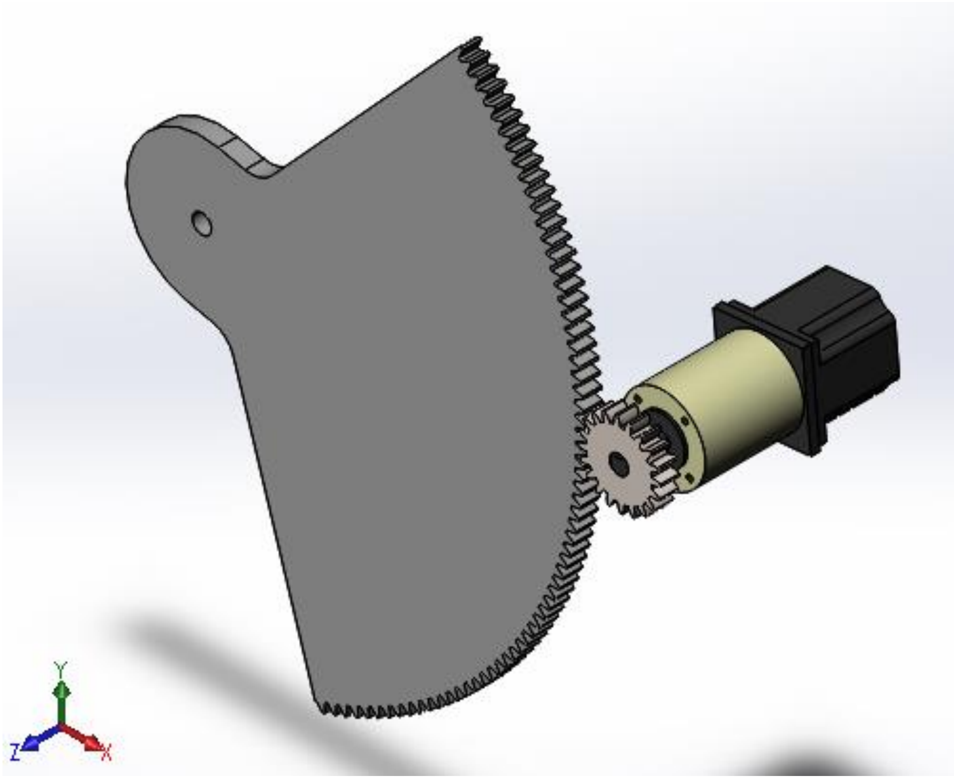


Figure 33 Launch Rail Gearing System

Figure 34 Planetary Geared Stepper Motor Used to Raise Launch Rail

Table 3 Launch Rail Raising System Stepper Motor Specifications

Manufacturer Part Number	23HS22-2804S-PG47
Motor Type	Bipolar Stepper
Gearbox Output Step Angle	0.0386 deg.
Gearbox Output Holding Torque	29.5 ft-lb
Gear Ratio	46.656:1
Gearbox Mech. Efficiency	73%
Rated Current/phase	2.8 A
Recommended Voltage	24-48 V

Launch Rail

The chosen launch rail is extruded 6105-T5 aluminum from Strongwell Corporation with a 1.5x1.5 inch t-slot cross-section and 74 inches in length. For the given rocket weight and rail length, the bending moment at the rail hinge was determined to be 120 ft-lb. Using the moment of inertia provided by the manufacturer, the maximum bending moment in the launch rail was determined to be 4110 psi. The yield stress for 6105-T5 aluminum given by the manufacturer is 35,000 psi, so the expected loading is well within the limit. The rail buttons will be matched to fit the launch rail cross-section.

Igniter Insertion System

To insert the igniter, the linear actuator system shown in ***Figure 35*** will be used. The 17HS15-0404S stepper motor, shown in ***Figure 36***, will be attached to a threaded rod via a small coupler. The rod will thread through a plate that is prevented from rotating by the two parallel guides. Attached to the nut will be a dowel holding the igniter. As the stepper motor turns, the plate/dowel assembly moves upwards, inserting the igniter into the base of the rocket.

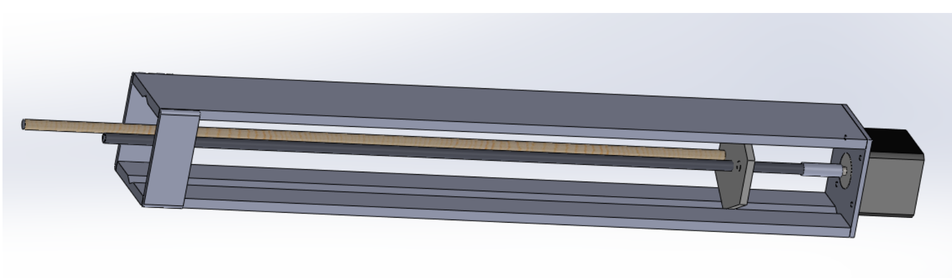


Figure 35 Igniter Insertion System

Figure 36 17HS15-0404S Motor Used to Insert the Igniter

Table 4 AGSE Mass Summary

Element	Weight (lb)	Mass (slug)
AGSE Base	74.41	2.31
Motor Blast Shield	6.57	0.20
Launch Gearing Assembly (with motor)	19.8	0.61
Launch Rail Pivot Support	15.21	0.47
Launch Rail	10.76	0.33
Ratcheting Steps	29.15	0.91
AGSE Base Legs	11.71	0.36
Arm Assembly	3	0.09
Support Bar	13.21	0.41
Igniter Assembly	2.5	0.08
Total	201.57	6.26

Computer Vision

A USB 2.0 camera mounted on the wrist of the robotic arm will be used to locate the sample. This subsystem requires digital image processing to find the sample, and translate the sample's image properties into coordinates in a space domain.

Figure 37 Sentech USB 2.0 Camera

For the camera, the Sentech STC-MC36USB-L2.3 Micro CMOS USB 2.0 Camera, as seen above in ***Figure 37*** was selected for its light weight, 26g, its low image resolution, and plug and play connectivity. Because the system will be on a BeagleBone Black, the image cannot be extremely pixel dense. A USB 2.0 camera offers a good medium for having enough images to pick out the sample and not too many so that the BeagleBone cannot process the image.

The image processing system will be executed in C++ on the BeagleBone. C++ was chosen so some functions can be developed in Simulink and autocoded, using MATLAB's embedded coder, into executable C++ code. The whole system will use some code developed by the team and some code taken from OpenCV. The source of some code will be somewhat decided by which MATLAB functions can be autocoded by the embedded coder. For example, imread is a MATLAB functon that translates a jpg into a red green blue matrix. Imread is not supported by the embedded coder so translating images from the camera into a red green blue matrices will be done by code found in OpenCV.

The basic flow of the system will be: Taking a still image with the camera, finding the PVC pipe in the image, relating the size of the PVC in the image to a calibration curve to find the distance from the camera to the PVC pipe, calculating arm movements to move the claw and camera closer to the sample, and then taking another image to get a more accurate distance calculation. The claw and camera will most likely move half of the calculated distance from the camera to the sample before taking the next image. Once the distance is at a certain threshold, the arm will instructed to complete the movement to the sample and capture it. The distance threshold might be related to the reach of a directed IR distance sensor mounted next to the claw. This sensor may not be necessary for the system, but it could add significant accuracy for the claw guidance so its usefulness will be carefully considered before CDR.

The team has developed some MATLAB functions that have successfully picked PVC pipe from a grassy background. The current method of image processing is fairly simple, so some parts may be replaced by more complex processing tools that can handle a wider variety of situations. The current script takes a red, green, blue color map and translates that into an intensity spectrum. The intensity map is searched for the maximum value which correlates to the whitest pixel in the image. Assuming the PVC pipe makes up the whitest pixels, the pixels with intensities close to the maximum are labeled as foreground. ***Figure 38*** shows an image before processing. ***Figure 39*** shows which pixels are labeled as foreground. A blob detection algorithm then searches the image for groups of adjacent foreground pixels. The preliminary blobs can be seen in ***Figure 40***. Once the blobs are formed, a grouping algorithm labels adjacent blobs into a common blob. These bigger blobs can be seen in ***Figure 41***. The properties of the blobs will be processed to identify the blob representing the PVC pipe. With the PVC blob identified, the size of the blob can be related to the distance of the sample from the camera.

Figure 38 Unprocessed PVC on Grass Picture

Figure 39 Foreground Separation

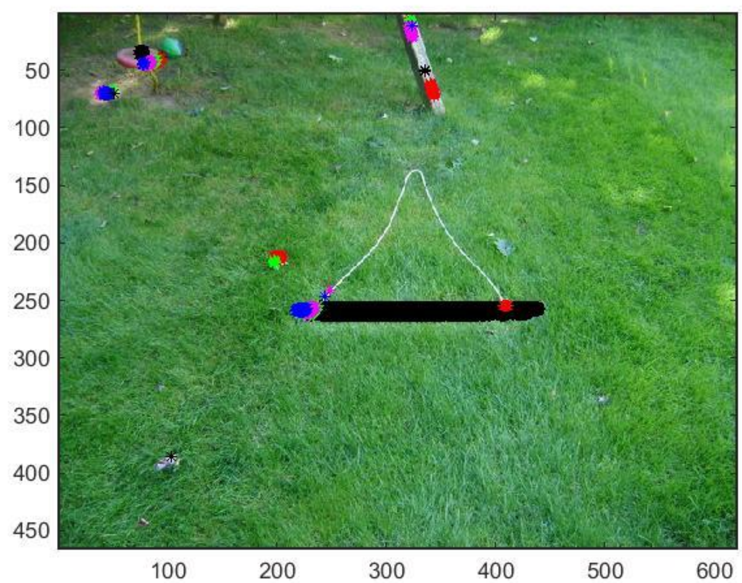


Figure 40 First Blob Sweep

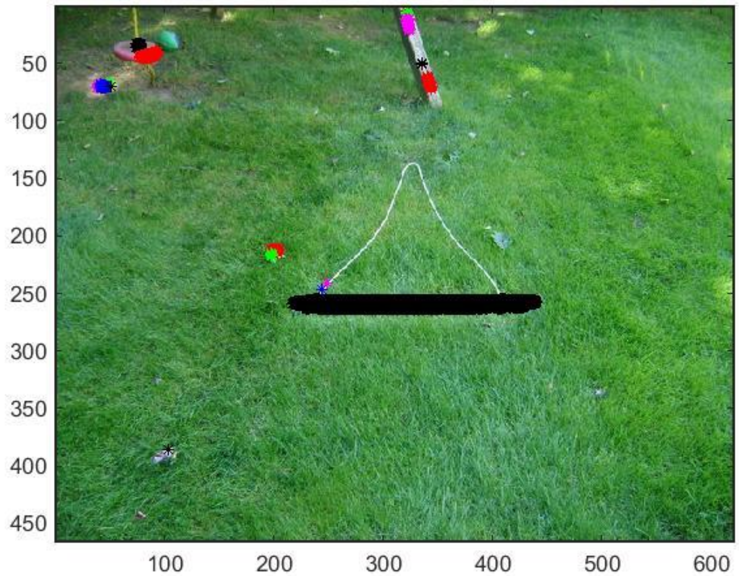


Figure 41 Second Blob Sweep

4.1.3. Performance Characteristics for System and Subsystem

A successful AGSE system will autonomously identify the sample, grab the sample, place the sample in the rocket, seal the rocket, raise the rocket, and insert the igniter. The BeagleBone Black will handle the sequencing of the tasks and schedule tasks based on which tasks have been completed. ***Figure 42*** and ***Figure 43*** illustrate the AGSE and launch vehicle integration for both horizontal and vertical orientations.

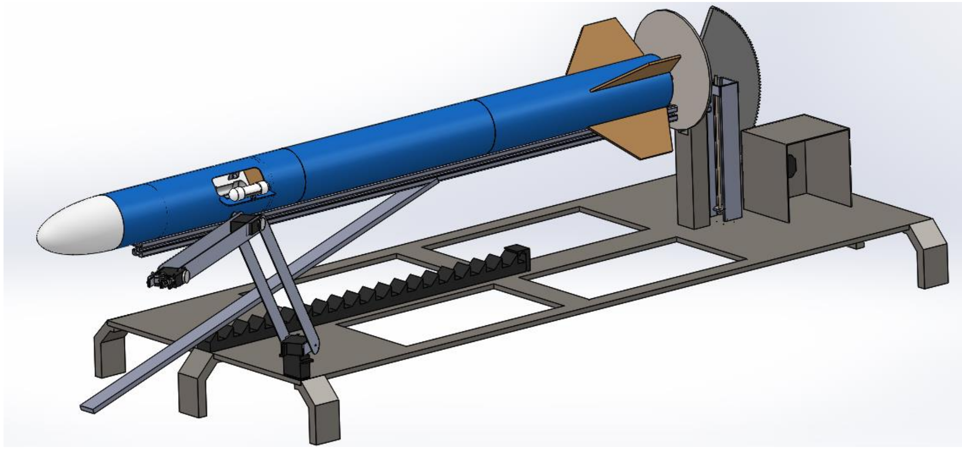


Figure 42 Horizontal AGSE Position

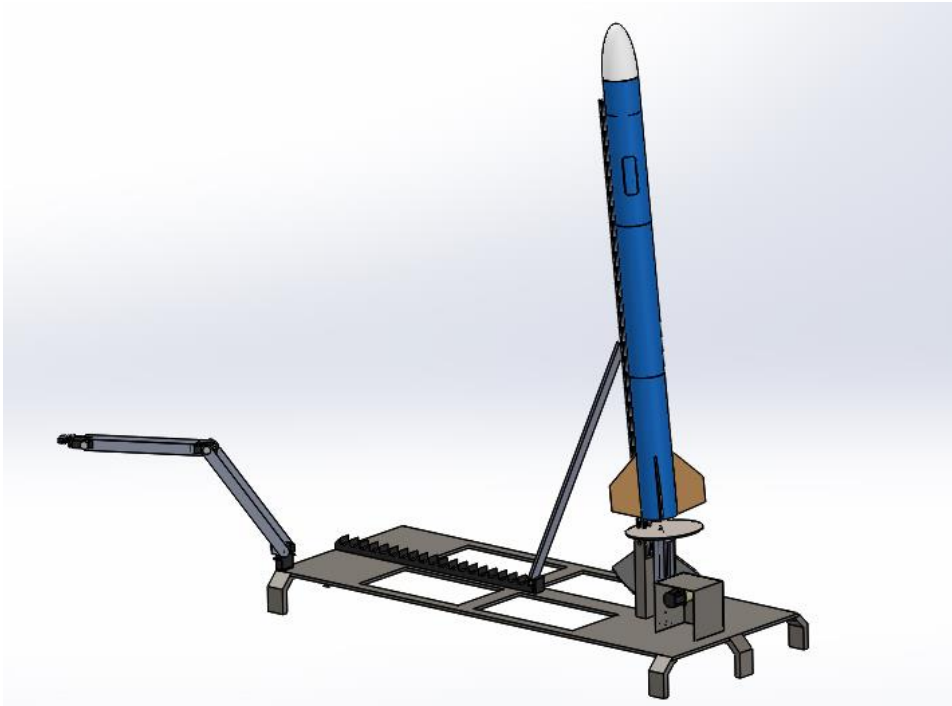


Figure 43 Vertical AGSE Position

4.1.4. Verification Plan

The team will complete a variety of experiments to confirm the AGSE can complete all tasks, and some of these experiments will be documented. One such experiment will relate the sample's image properties to the sample's distance, and the abstract for this experiment is given below.

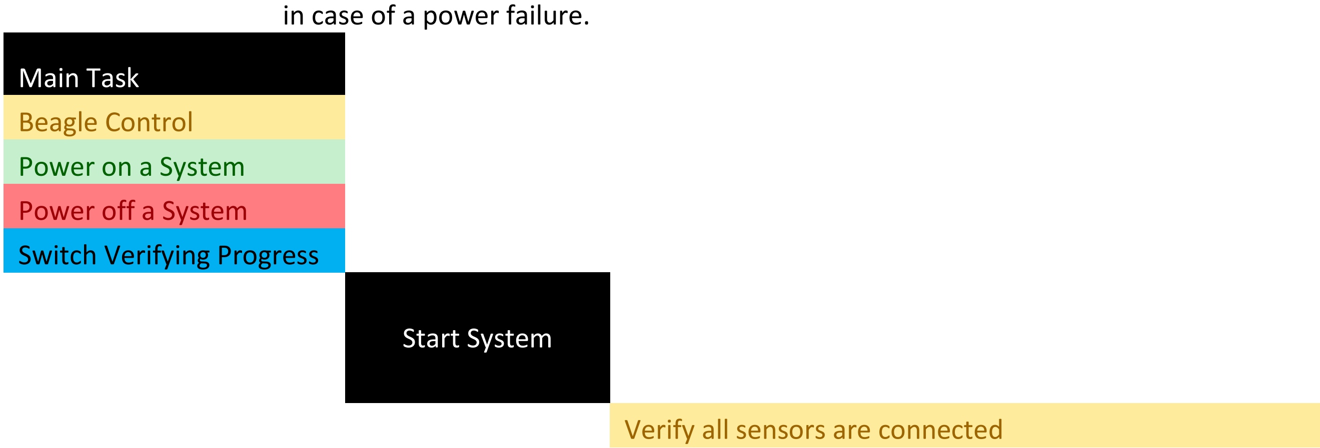
Image processing is a key component of the AGSE system. Based on NASA's requirements, the AGSE must autonomously identify, acquire, and finally place the sample into the rocket. The design for the NCSU AGSE involves placing a USB camera on the end of the robotic arm. The image processing algorithm will grab single frames from the camera, identify the sample in the image, and calculate the distance from the camera to the sample. The algorithm picks out the whitest pixels in the frame and then groups the clusters of pixels into blobs. The system will then filter the blobs until the blob representing the sample is identified. In order to find the distance from the camera to the sample, the system must relate the known, actual size of the sample to the size of the sample blob in the image.

This experiment will form a calibration curve between the size of the blob in the image to the distance away from the camera. The initial goal of the AGSE is to be able to grab the sample when it is placed directly in front of the arm up to a distance, along the ground, of 19.5 inches away. For this experiment, pictures will be taken by the camera at distances between three and twenty inches in increments of one half inch. These pictures will be taken at three different heights: 3, 12, and 24 inches. The image processing system will then process these images and find the size of the sample blob. This information will form a curve relating the size of the blob to the distance to the sample. After the curve is produced, new images will be taken at straight-line-distances of varying heights between 3.5 and 21 inches at half inch increments. These pictures will also be processed and the blob sizes will be fed into the curve to produce predicted distances to the sample. Ideally, these predicted distances will be within a quarter inch of the actual distance to the sample.

Another experiment to verify that the AGSE can complete the required tasks involves the stepper motors used to lift the launch rail and insert the igniter. The advantage of stepper motors over regular DC motors is that they can be made to rotate very precise angles. Unfortunately, stepper motors have no built in feedback sensor to relay their position. Therefore, the angular rotation (i.e. number of steps) required to achieve a certain movement must be determined ahead of time. The steps required to raise the launch rail and insert the igniter will be determined from the given geometry. Then, experimental testing will be done to ensure that these calculated values agree with the actual required number of steps. This calibration is crucial to ensure that the components reach the desired position and are not stressed by over-stepping.

4.1.5. Preliminary Integration Plan

Figure 44 provides some details into the flow of the AGSE system. The BeagleBone will be central to the monitoring, scheduling, and control of the system. To monitor the progress of the system, the BeagleBone will interface with a system of switches that monitor that relay task completeness. The key tasks to be verified by switches will be grabbing the sample, placing the sample in the rocket clamp, closing the door of the rocket, verifying rocket was erected to correct position, and verifying the igniter is the correct position. These tasks, colored blue in ***Figure 44*** will conclude either with compression of a switch or touch sensor that will complete a circuit and send a signal to the BeagleBone. With information of which tasks have been completed, the BeagleBone can schedule and control procedures for the next task. The completion of each task will also be electronically stored on the BeagleBone so the system knows where to resume in case of a power failure.



Grab the sample

- Power on arm and camera
- Arm and imaging startup program
- Find sample
- Move arm closer to sample
- Find Sample, move, repeat until close
- Grab arm with hand. Triggers touch sensor on hand.

Insert sample in clamps

- Move sample to clamp on rocket with arm
- Push sample into clamp in door of rocket.
- Trigger switch for clamp
- Release hand.
- Close rocket door with arm.
- Trigger switch to verify door is closed
- Move arm to preset location out of rocket path.
- Press switch to verify its in safe place.
- Power off arm and camera

Raise the rocket

- Power on step motor
- Run step motor
- Trigger switch when rocket at desired position
- Power off step motor

Insert the igniter

- Power on igniter stepper motor
- Operate igniter motor until igniter is inside rocket motor
- Trigger igniter insertion switch when igniter at desired position
- Power off igniter motor

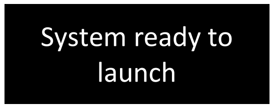


Figure 44 AGSE Progression Overview

A critical subsystem couple is between the imaging system and robotic arm. The imaging system will take a series of pictures and determine the distance from the camera to the system. The USB camera will be mounted on the gripper of the arm and will experience the full degrees of freedom of the robotic arm.

At the start of the process the camera will be at a set initial position facing the sample. An initial picture will communicate the movements necessary to rotate the base of the arm and pitch the gripper/camera so the sample will be centered in another picture. The next picture will contain a centered sample and will be used to calculate the distance from the camera to the sample. This distance will be relayed to the arm. With the sample's location in space, the arm will move half of the total in-line distance closer to the sample and will orient the camera so the sample is centered in the next picture. At the halfway point, another image will be processed to determine the distance between the sample and the camera. The arm will be moved so its next location is four inches directly above the sample. The camera will take a picture at this position to confirm it is four inches away, and this image will determine the rotation needed by the wrist to center the gripper on the sample. After the gripper is rotated to match the orientation of the sample, another picture will be taken and processed to confirm the gripper will reach the sample. After this final picture, the arm will move to grab the sample.

4.1.6. Precision of Instrumentation, Repeatability of Measurement, and Recovery System

The accuracy of the robotic arm is crucial to the AGSE completing its tasks. The arm on the AGSE is going to be used to obtain the sample, insert the sample into the rocket, and close the hatch door to the sample compartment. Because the Student Launch challenge is based around obtaining and restraining the sample, a failure with the robotic arm cause the entire mission of the AGSE to be a failure. The current plan is to have a look-up table of x-y-z coordinates in space and the corresponding angles required to reach that location in space. In order to obtain the sample, the arm will have to be able to move to an exact specified location. Therefore, an experiment will be conducted to test and calibrate the accuracy of the arm.

All of the angles need to be defined with respect to a reference orientation of the arm. For simplicity, this location was taken to be the arm fully extended, parallel to the ground. Furthermore, according to manufacturer's specifications, the neutral position of the servo corresponds to a pulse of 1500 µs. Therefore, the first aspect of the experiment will be to calibrate the servos so that a pulse width of 1500 µs causes the arm to be fully extended. Once the zero position has been established, the arm will be repeatedly commanded to go to a position in space that is 19.5 inches out and 11.75

inches down, measured with respect to the shoulder point of rotation. The distance between this location in space and the exact location the arm moves to will indicate the accuracy and repeatability of the movement of the arm. This location was chosen because that is the general location where the sample will be placed on the day of the competition. In between each test, the arm will also be commanded to move back to its initial zero position. This process will be done a minimum of 5 different times in order to collect enough data, and success will be measured if the arm can consistently move to the correct location, within three tenths of an inch.

The above portion of the experiment will test the consistency of the arm, but that actual arm will also need to insert the sample into a c-clamp. Therefore, initial testing of the arm will also have the arm start with the sample in the gripper and practice moving to and inserting the sample into the c-clamp. This test will also be completed a minimum of 5 times to ensure that the arm can consistently insert the sample into the rocket. Further testing will need to be done to ensure that the arm can also close the hatch door.

An additional experiment will performed to test the integration of the imaging system with the arm. The arm will be programed to move to a certain location in space where the sample is located, pausing at predetermined increments before it reaches the desired location. Because the arm will have four distinct phases during the competition, this experiment will have the arm move a quarter of the distance to the sample for the first stage. The second stage will have the arm move another quarter distance to the sample, ensuring that the sample is centered in the image. The third stage will have the arm positioned 4 inches directly above the sample and rotate the wrist so that the gripper is perpendicular to the length of the pipe. The fourth stage will have the arm grab the sample. Error in the system will be measured by determining the difference between the desired location and the actual location. Furthermore, by projecting the shadow of the arm onto the wall, the angle between the sections of the arm and the horizontal can be determined to quantify the error as well. An acceptable error will be if the distances are within 0.25 inches of each other, and the angles within 5 degrees for this initial testing.

If there is a power loss to the whole system a complete reboot will be required. The BeagleBone will have the startup program that will start on a system reboot. From the ground station the process to find and load the sample will be restarted.

4.1.7. AGSE Electrical Schematics

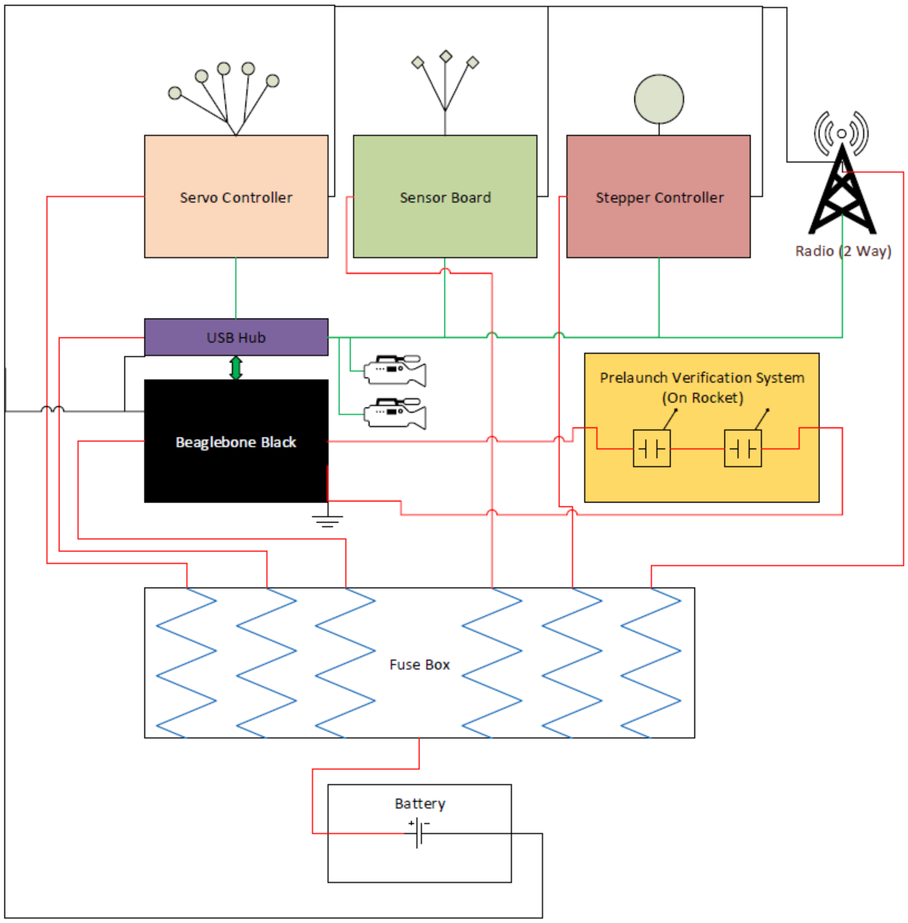


Figure 45 AGSE Electrical Schematic

Legend:

- Blue zig zag lines: resistors (resistance not yet determined)
- Black connectors: Ground/Negative (does not include connections to motors and sensors)
- Red connectors: Positive
- Green connectors: USB connection

The fuse box will control voltage input to any device that requires direct power (note: some USB devices do not need a direct power source). There will be two separate power supplies. One 37 V, three cell, LiPo battery will be for the stepper motor used to raise the rocket and the stepper motor used to raise the igniter. The second battery system will be a 11.1V, three cell, LiPo battery used to power the BeagleBone Black, robotic arm servos, robotic arm controller, and stepper controllers. We will be using a BeagleBone Black (BBB) Linux Computer to do all of our primary processing onboard the AGSE. We feel the BBB has the necessary specs to process images, control motors, process sensor data, and communicate with the ground station. The BBB will utilize primarily USB connections to the devices we need. A USB hub (marked as hub) is needed since the BBB has only one USB output. A Phidgets servo controller board will be used to control the six servos on the robotic arm. A Phidgets sensor board will convert sensor input (touch sensors) into readable signals for the BBB (additional sensors may be added). A Phidgets stepper controller will be used to control a high torque stepper motor to raise the rocket into launch position. There will two cameras onboard the AGSE. One camera will be on the arm and used to identify where the sample is. The second camera is purely for viewing the entire system remotely, and has no input on how the system performs. A 2-way Digi XTend radio will be used to radio stats and a video feed back to the ground station. We will only transmit to the rocket for pausing, resuming, or aborting in case of an emergency. We will also have a remote dead switch inside the fuse box (completely independent of the BBB system) that will cut off power to the entire system in case of an emergency. The Prelaunch Verification System (PVS) is used to make sure that the sample is safely contained within the rocket. The BBB will make sure that the sample has been inserted, and the door has been shut.

4.1.8. Key Components of AGSE to Achieve Objectives

The key components of the AGSE are the BeagleBone Black, the robotic arm, the camera system, the erector system, and the igniter insertion device. The mission success depends highly on these systems working together autonomously.

4.2. AGSE Concept Features and Definition

4.2.1. Creativity and Originality

Although all of the individual subsystems have been done before in other projects, they are all put together in a way that makes the team's design unique. For example, the rocket will be raised for launch using a large gear system, and the igniter will be inserted with a threaded rod system. These two systems provide an effective mechanical means of preparing the vehicle for launch, without increasing the modes of failure due to a complex electrical system of motors and actuators. Furthermore, the arm will be able to adapt to different orientations of the sample through the use of the imaging system. Rather than hard coding in the location of the PVC and only having the arm move to a specific location, the arm will move to an original location each time.

4.2.2. Uniqueness or Significance

Success of the AGSE will prove the viability of the subsystems to be used in actual missions. Using image processing to identify items of interest on the Martian surface is a likely scenario. Therefore, the systems used in this project will show how this system can be implemented into a sample return mission.

4.2.3. Suitable Level of Challenge

The current plan provides various degrees of challenge to the team. For example, rather than hard code the location of the payload, an imaging system is going to be used that can identify the sample in a varying location. Therefore, the AGSE will determine where the sample is, and how it has to move the robotic arm to retain the sample. This system requires a large amount of sophisticated code in order to accomplish its goal and is not a simple task. Furthermore, the arm is to be used to close the hatch door to the sample compartment. In addition to having to coordinate the movement of the arm, the locking mechanism has to be weak enough to allow the arm to close the sample door, yet strong enough for to remain closed during flight.

4.3. Science Value

Since the Maxi-MAV challenge is designed to model the conditions on Mars, the systems used must be able to work under similar conditions. Therefore, the systems used in this project may ultimately be able to be scaled up and used in actual missions. The sections below describe how each system contributes to scientific advancement in the field of Aerospace.

4.3.1. AGSE Objectives

The goal of the AGSE is to retrieve a sample and insert it into the rocket. On Mars, or any other distant body, a similar process will need to be done so that the soil sample can be processed on Earth. Therefore, the processes investigated in the AGSE portion of the experiment have a direct correlation to actual systems that can be used. Having a robotic arm obtain and secure the sample in the rocket is a feasible system.

4.3.2. AGSE Success Criteria

The AGSE will be successful if it can identify, capture, and retain the sample. After these tasks have been completed, the vehicle will then be erected for launch. Success for the AGSE will only be obtained if these tasks are completed. Success with the AGSE will prove the viability of the system as a whole to be implemented in other tasks, such as missions to Mars.

4.3.3. Experimental Logic, Approach, and Method of Investigation

All of the experiments described above are physical tasks that will need to be completed by the team. By testing each of the crucial subsystems (image processing, arm movement, recovery system deployment), overall success of the project can be insured. It is important that all modes of failure are analyzed to account for any means of failure. Therefore, each test will be performed several times in order to collect sufficient data and prove the repeatability of the processes. It is important that viable data be obtained from each experiment so that the real system will work correctly. As such, each experiment will be approached as if the test was for the actual competition. Improper testing would lead to inaccurate data and failure of the mission, detracting from the scientific value of the project.

4.3.4. Tests and Measurement, Variables, and Controls

The data will be collected using accurate measurements, such as with digital calipers and a gram scale. As described above, the variables to be tested are the amounts of black powder needed, and the accuracy of the robotic arm and imaging systems. Since all of the test are experimental in nature and are rated on a success/failure scale, control tests cannot be used to establish the baseline for the experiments.

4.3.5. Relevance of Expected Data

The data collected during the experiments will show if the current plan will work. The data is critical to the success of the project, and is thus relevant to the tasks at hand.

4.3.6. Preliminary Experiment Process Procedures

The preliminary experiments are described in detail above in the two Verification Plan sections, Preliminary AGSE Integration Plan, and Precision of Instrumentation sections.

5. Project Plan

5.1. Development Schedule/Timeline

Event/Task	Start Date	Finish Date
Completed PDR Submission	11/5/2014	11/5/2014
PDR Team Teleconference	11/18/2014	11/18/2014
Critical Design Review (CDR) Writing	11/6/2014	12/15/2015
Build Subscale	11/5/2014	11/20/2014
Ejection Testing on Subscale	11/20/2014	11/20/2014
Initial Calibration of Arm (Experiment)	11/14/2014	11/28/2014
Prepare Subscale for Launch	11/21/2014	11/21/2014
Subscale Launch	11/22/2014	11/23/2014
Camera Experiment	11/24/014	12/1/2014
NCSU Winter Break (no building access)	12/16/2014	1/6/2015
CDR Writing	1/7/2015	1/15/2015
Completed CDR Submission	1/16/2015	1/16/2015
Arm + Camera Experiment	1/16/2015	1/23/2015
Full Scale Construction	1/17/2015	2/17/2015
AGSE Construction	1/17/2015	3/1/2015
CDR Team Teleconference (Tentative)	1/21/2015	2/4/2015

Flight Readiness Review (FRR) Writing	1/17/2015	3/15/2015
Full Scale Launch (Tentative)	2/22/2015	2/23/2015
YMCA Kite and Rocket Day	3/7/15	3/8/15
Completed FRR Submission	3/16/2015	3/16/2015
FRR Team Teleconference (Tentative)	3/18/2015	3/27/2015
Finish Construction	3/31/2015	3/31/2015
Prepare for Competition	3/31/2015	4/6/2015
Sigma Gamma Tau Boy Scout Merit Badge Event	4/4/2015	4/4/2015
Team Travel to Huntsville, Alabama	4/7/2015	4/7/2015
Launch Readiness Review (LRR)	4/7/2015	4/7/2015
NASA Safety Briefing	4/8/2015	4/8/2015
Rocket Fair and Tours of MSFC	4/9/2015	4/9/2015
Launch Day	4/10/2015	4/10/2015
Backup Launch Day	4/12/2015	4/12/2015
Senior Picnic (full scale launch)	4/27/2015	4/27/2015
Post-Launch Assessment Review	4/29/2015	4/29/2015
Winning Team Announced by NASA	5/11/2015	5/11/2015

5.2. Budget

The current budget accounts for, but is not limited to the following:

	Item	**Amount**	**Total Price**
AGSE	BeagleBone Black	1	$40
	Phidgets Stepper Motor Controller	1	$95
	Phidgets Servo Controller	1	$50
	Phidgets Sensor Board	1	$90
	Nema 17 Bipolar Stepper	1	$10
	Nema 23 Geared Stepper Motor	1	$60
	USB hub	1	$10

	Thunder Power 37 V Battery	1	$340
	12V Step Down to 5V Power Module	1	$10
	2.1 mm Coax Power Plug	1	$5
	12V Step Down to 6V Power Module	1	$10
	Thunder Power 12 V Battery	1	$100
	Xtend Radio Units	2	$600
	Camera (for video feed)	1	$30
	Camera (for image processing)	1	$100
	Steel Plate for gears (0.25"x24"x24")	1	$60
	Aluminum Railing	30 ft	$100
	Brackets	15	$80
	Lynxmotion Servo Controller (for arm)	1	$40
	Aluminum square beam (for ratcheting stops)	4 ft	$10
	Miscellaneous hardware (nuts/bolts/washers)	--	$100
	Gripper for Robotic Arm	1	$40

	RobotShop M100 RAK Robotic Arm	1	$600
	Electronic sensors	--	$100
	Balsa wood dowel	1	$5
	Threaded Rods	5 ft	$35
Rocket	LOC 4" Kraft Paper Body Tube	2	$25
	ARR Standard Coupler 5.5” x .077 wall x 12”	1	$20
	ARR Airframe 5.5” x .077 wall x 48” Airframe/MMT	1	$60
	ARR Airframe 5.5” x .077 wall x 72” Airframe	1	$90
	LOC 3.814" Coupler	3	$15
	Fiberglast 3k, 2 x 2 Twill Weave Carbon Fiber Fabric (1 yard), 50'' wide, .012" Thick	1	$60
	Aircraft Spruce Domestic Birch Plywood ¼” x 4 x 4	1	$120
	Aircraft Spruce Domestic Birch Plywood⅜” x 4 x 4	1	$140
	Epoxy and hardener	1	$50

	Paint	--	$30
	Rail buttons	4	$15
	StratoLogger Altimeter	4	$320
	GPS Bee	3	$95
	K motor (full scale)	2	$200
	J350W-M propellant (subscale)	2	$125
	Wires	--	$30
	Connectors	--	$20
	Nose cone (full scale)	1	$60
	Nose cone (subscale)	1	$35
	Motor casing (full scale)	1	$100
	Motor casing (subscale)	1	$65
	Kevlar shock cord	60 ft	$60
	18" Fruity Chute Classic Elliptical Parachute	1	$55
	48" Fruity Chute Classic Elliptical Parachute	1	$115
	36" Fruity Chute Classic Elliptical Parachute	1	$85

	Black powder	1 lb	$20
	RATTworks ARRD	1	$95
	Igniters	5	$10
Other	Travel expenses (hotel, rental car, gas)	20 people	$3,000
	incidentals (replacement tools, hardware, safety equipment)	--	$1,000
	Shipping costs		$750
Subtotal	--	--	$9,585

5.3. Funding Plan

The budget needed to complete this project has been started. The club received $2,000 from the Engineering Technology Fee Fund from the Mechanical and Aerospace Department at North Carolina State University. The Engineering Council at NCSU has also granted the club $1,500 for the fall semester through a proposal, a presentation, and an appeals presentation. The club is looking to receive another $1,500 in the spring semester from the Engineering Council. The Student Government Appropriations committee has given $1,000 through a proposal and interview for the spring semester. Two proposals, for competition and for senior design, were submitted to the NC Space Grant. NC Space Grant has granted the club $5,000 for the competition and $2,000 for senior design.

Table 5 Summary of Project Funding

Source	Amount

NCSU MAE Department ETF Funding	$2000
NCSU Engineering Council	$3000
Student Government Appropriations	$1000
North Carolina Space Grant	$7000
Total	$13000

Educational Plan

Tripoli Summer Low-Mid Power Launches

During the summer, NCSU High Powered Rocketry Club attended Tripoli-hosted low-mid power rocket launches on May 24th, June 28th, July 26th, and August 16th. During these launches the club members Chris Celestino, Emily Gipson, Jamie Region, Josh Pickles, and Will Martz assisted the Tripoli organization with setting up and taking down the launch site in Butner, NC, setting up an information table for kids and adults to learn about High Powered Rocketry, launching our subscale demonstrators from previous years, and helping to recover rockets. There were between 50-150 people attended each of these launches.

Location: Perkins Field, Butner, NC 27509

Dates: May 24th, June 28th, July 26th, and August 16th

GE Aviation – Manufacturing Day

Chris Celestino and Collin Bolton attended GE Aviation's Manufacturing day at the GE Aviation plant in Durham, NC. This event was open to a number of students from the surrounding area and had approximately 80 high school students from 4 different high schools (including early college STEM school at NC State) and another 25 students from the NC State Career Development Center. These students made up a majority of the audience, but adults participated as well. Roughly 150 people were in attendance.

NC State's High Power Rocketry Club hosted a display table for an info fair to provide some "next step" ideas for students who are interested in aerospace manufacturing. The members engaged participants about NC State Aerospace Engineering, Rocketry, and the High Power Rocketry Club with a table top booth/display, hands-on and interactive elements, and hand-out information about the club and NC State's Aerospace program.

Location: GE Aviation 3701 S. Miami Boulevard, Durham, NC 27703

Date: Friday, October 3rd 10:00 – 1:00PM

YMCA Kite and Rocket Day

The High Powered Rocketry Club is planning on continuing the tradition of being a part of the YMCA Kite and Rocket Day in the spring of 2015. The Club plans to set up an informational booth at Carter Finley Stadium to assist young rocketeers with assembling and launching model rockets. Last year's event had over 200 kids attend the Kite and Rocket Day and we expect many more this year. The details will be available as the event gets closer in the spring.

Location: Carter Finley Stadium, 4600 Trinity Rd. Raleigh, NC 27607

Date: March 7-8th, 2015

Sigma Gamma Tau Boy Scout Merit Badge Event

The club is also planning on partnering with NCSU's chapter of Sigma Gamma Tau to host their annual Boy Scout Merit Badge Event in the spring of 2015. On the morning of this event, the club launches a model rocket for the enjoyment of the Boy Scouts and their families. Sigma Gamma Tau then gives a presentation for those attending before the Space Exploration badges are awarded. This even takes place at NCSU's campus and involves around 30-40 Boy Scouts and their families. The details of this event will be finalized in spring 2015.

Location: North Carolina State University's campus, Raleigh, NC 27695

Date: April 4th, 2015

6. Conclusion

With the conclusion of the PDR, the North Carolina State Rocketry Team, Tacho Lycos, will move ahead with the fabrication of the subscale launch vehicle. During this time, multiple experiments will be in progress as parts and materials are ordered for the full scale rocket and AGSE systems. The experiments will be used to ensure the components function properly on their own and that data is able to be successfully acquired.

Appendix 1 Milestone Review Flysheet

Milestone Review Flysheet

Please see Milestone Review Flysheet Instructions.

Institution	North Carolina State University	Milestone	PDR

Vehicle Properties	
Total Length (in)	78
Diameter (in)	5.5
Gross Lift Off Weight (lb)	15.25

Motor Properties	
Motor Manufacturer(s)	Animal Motor Works
Motor Designation(s)	K535RR
Max/Average Thrust (lb)	142.4 / 119.7

Airframe Material	BlueTube 2.0
Fin Material	Plywood/Carbon Fiber
Drag	

Total Impulse (lbf-sec)	324.1
Mass (before, after burn)	3.44 / 1.75
Liftoff Thrust (lb)	33.2

Stability Analysis	
Center of Pressure (in from nose)	57.90
Center of Gravity (in from nose)	47.4
Static Stability Margin	1.91
Thrust-to-Weight Ratio	7.85 : 1
Rail Size (in)/ Length (in)	1.5 / 66
Rail Exit Velocity (ft/s)	45

Ascent Analysis	
Maximum Velocity (ft/s)	547
Maximum Mach Number	0.49
Maximum Acceleration (ft/s^2)	266
Target Apogee (1st Stage if Multiple Stages)	3240 ft
Stable Velocity (ft/s)	44
Distance to Stable Velocity (ft)	3.85

Recovery System Properties				
Drogue Parachute				
Manufacturer/Model	Fruity Chutes Drogue Chute			
Size	18 in			
Altitude at Deployment (ft)	3000			
Velocity at Deployment (ft/s)	0			
Terminal Velocity (ft/s)	72			
Recovery Harness Material	Braided Kevlar Cord			
Harness Size/Thickness (in)	0.23			
Recovery Harness Length (ft)	6.8			
Harness/Airframe Interfaces	Forward: AARD on Sample/Nosecose section Aft: U-bolt on middle airframe			
Kinetic Energy of Each Section (ft-lbs)	Section 1	Section 2	Section 3	Section 4
	1400	N/A	N/A	N/A

Recovery System Properties				
Main Parachute				
Manufacturer/Model	Fruity Chutes Classic Elliptical			
Size	36 in / 48 in			
Altitude at Deployment (ft)	1000 / 700			
Velocity at Deployment (ft/s)	72			
Terminal Velocity (ft/s)	21/24			
Recovery Harness Material	Braided Kevlar Cord			
Harness Size/Thickness (in)	0.23			
Recovery Harness Length (ft)	5.8/6.9			
Harness/Airframe Interfaces	Forward: U-bolt on middle airframe Aft: U-bolt on fin section bulkhead			
Kinetic Energy of Each Section (ft-lbs)	Section 1	Section 2	Section 3	Section 4
	62	61		

Recovery Electronics	
Altimeter(s)/Timer(s) (Make/Model)	Perfectflite Stratologger SL100
Redundancy Plan	Apogee charges will have a 2 s delay. Main redundant charge will be programmed for 600 ft AGL at 125% primary charge size.
Pad Stay Time (Launch Configuration)	1 hour

Recovery Electronics	
Rocket Locators (Make/Model)	Digi XBee-Pro XSC
Transmitting Frequencies	***Required by CDR***
Black Powder Mass Drogue Chute (grams)	TBD
Black Powder Mass Main Chute (grams)	TBD

Milestone Review Flysheet

Please see Milestone Review Flysheet Instructions.

Institution	North Carolina State University	Milestone	PDR

Autonomous Ground Support Equipment (AGSE)

Capture Mechanism	Overview A purchased robotic arm will use an image recognition system based on color identification to locate and direct itself to the sample to be grappled.
Container Mechanism	Overview A combination of a Quik Klip clamp mounted to the inside of the payload compartment door and a foam mold attached to a sled in the payload compartment will secure the sample.
Launch Rail Mechanism	Overview The launch rail will be raised by a geared stepper motor. While being raised, the rail will be supported by a ratcheting brace in case of a loss of power. Once fully raised, a pin will engage into a hole in the side of the launch rail sector gear to lock it in place.
Igniter Installation Mechanism	Overview Stepper motor powered linear actuator will raise the electric match igniter into the rocket on a wooden dowel.
CG Location of Launch Pad (in inches) When Rail is Horizontal (Use Base of Rail as the Reference Point)	25.1 inches
Moment Analysis	Because of the stable CG location the moment generated from the lifting of the rocket will not tip the AGSE system.

Payload

Payload 1	Overview The payload will be made of 3/4 x 3 inch PVC tubing filled with sand and weigh approximately 4 oz. The payload will be a cylindrical shape approximately with a 3/4 inch diameter and a 4.75 inch length. Ends of the tubing will be secured with domed PVC caps.
Payload 2	Overview N/A

Test Plans, Status, and Results	
Ejection Charge Tests	Ejection charges will be sized specific to the compartment to be separated. Charges will be constructed with Black powder in a plastic vile with an E-match secured in the vile by wadding. Each altimeter will be connected through a USB port to a laptop with the Perfectflite DataCap program. Charge ignition for main and drogue charges are capable of being separately fired at the users input. If the test is a failure, analysis will be conducted with new tests to follow.
Sub-scale Test Flights	The subscale flight test is planned for November 22nd, 2014 and will use a 70% scale model of the final full scale design. The parts have been ordered and the build will be started after the completion of the PDR.
Full-scale Test Flights	The full scale flight test is planned to take place in February/March 2015.

Milestone Review Flysheet

Please see Milestone Review Flysheet Instructions.

Institution	North Carolina State University	Milestone	PDR

Additional Comments

Appendix 2 FMECA Failure Modes

Structures

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Blue Tube Airframe	Cracks or breaks	Manufacturing defect	Individual sections	Unintended launch	1	Visual inspection prior to use

		Loads beyond design specification	structural integrity at risk	vehicle separation	1	Maintain vehicle within design specifications
		Damaged during handling			1	Adhere to proper handling procedure
		Improper maintenance			1	Pre/post launch inspections
Bulkheads	Separation of bulkhead from other structural members	Poor design	Unable to transfer loads	Increased loads on other structural members	2	FEA of bulkhead fixed support
		Manufacturing defect			2	QC of manufacturing process
		Loads beyond design specification			2	Maintain vehicle within design specifications
		Damaged during handling			2	Ensure analysis includes handling loads/adhere to proper handling procedure
		Improper maintenance			2	Pre/post launch inspections
	Damage/separation from parachute deployment	Poor design	Unable to support loads of chute deployment	Loss of safe and effective recovery system	2	FEA of bulkhead stress
		Manufacturing defect			2	QC of manufacturing process
		Loads beyond design specification			2	Maintain operations within design specifications
		Improper Maintenance			2	Pre/post launch inspections
	Non-compromising cracks	Poor Design	Potential for future damage	No system level safety effect	4	FEA of bulkhead stress
		Manufacturing Defect			4	QC of manufacturing process

		Loads beyond design specification			4	Maintain operations within design specifications
		Damaged during handling			4	Adhere to proper handling procedure
		Improper maintenance			4	Pre/post launch inspections
Fins	Damage from impact	Poor design	Loss of future fin use	Possible damage to other components	2	FEA
		Manufacturing defect			2	QC of manufacturing process
		Damaged during handling			2	Adhere to proper handling procedure
		Loads beyond design specification			2	Maintain operations within design specifications
		Improper maintenance			2	Pre/post launch inspections
Shear Pins	Breaking before charge detonation	Manufacturing defect	Loose assembly of compartment	Separation of vehicle compartments	3	QC of parts received
		Loads beyond design specification			3	Maintain vehicle within design specifications
		Improper maintenance			3	Use of new pins after each launch
Avionics Sleds	Detaches from secured position	Poor design	Damage to/loose wiring of avionics components	Loss of recovery system initiation	3	Design to ensure secure sled with redundancy
		Manufacturing defect			3	QC of manufacturing process

		Damaged during handling			3	Adhere to proper handling procedure
		Loads beyond design specification			3	Maintain operations within design specifications
		Improper maintenance			3	Pre/post launch inspections
Nose Cone	Non-compromising cracks	Manufacturing defect	Potential for future damage	No system level safety effect	4	QC of part received
		Damaged during handling			4	Adhere to proper handling procedure
		Loads beyond design specification			4	Maintain vehicle within design specifications
		Improper maintenance			4	Pre/post launch inspections
	Damage from impact	Manufacturing defect	Loss of future nosecone use	No system level safety effect	3	QC of part received
		Damaged during handling			3	Adhere to proper handling procedure

		Loads beyond design specification			3	Maintain vehicle within design specifications
		Improper maintenance			3	Pre/post launch inspections
	Pre-mature separation from other structural members	Damaged during handling	Potential for structural damage	Loss of controlled and stabilized flight	1	Adhere to proper handling procedure
		Improper maintenance			1	Pre/post launch inspections

Recovery

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Black Powder Charges	Deployment failure	Charge is too small	Unsuccessful parachute deployment	Rocket is not safely recovered	1	Complete experimental testing to ensure proper charge sizing
	Violent ejection causes accidental separation	Charge is too big			1	
Avionics	No power to avionics or igniters	Dead battery	No ejections	Rocket is not safely recovered	1	Use new batteries for each launch

	Interference from RF transmitter	Improper design	No ejections or mistimed ejections	Damage from high velocity ejection	2	Complete testing of electronic devices
	Bug in altimeter coding	Manufacturer defect		Large drift from early ejection	4	Test two altimeters for redundancy
Bulkhead and U-bolt	U-bolt failure	Improper attachment	Separation of rocket section from parachute	Rocket is not safely recovered	1	Make sure components are adequately constructed
	Bulkhead failure	Improper attachment			1	
Parachute deployment	Parachutes (3) fail to deploy correctly	Parachute tangling	Parachutes do not correctly deploy	Rocket is not safely recovered	1	Ensure that parachutes and shock cord are folded correctly
		Remote sensor of rocket section from parachutes			3	Construct the rocket so the wires are out of the way
		Parachute bags do not fully open			1	Fold bags correctly and make sure nothing can snag the parachutes
		Shock cord connections come loose			1	Check all shock cord
Exploding Eyebolt (ARRD)	Eyebolt fails to detonate	Improper wiring/attachment	Upper and middle airframes do not separate	Rocket is not safely recovered	1	Make sure components are adequately constructed
		Manufacturer defect			4	Test two eyebolts for redundancy

	Premature detonation	Improper wiring/attachment	Premature separation of connections between lower and middle airframe	Large drifting distance of lower airframe	3	Make sure components are adequately constructed
		RF interference			3	Complete testing of electronic devices

Aerodynamics

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Fins	Fins layout cause unexpected trajectory	Fins are not attached at the correct angle	Aerodynamic forces from fins are not the same from each fin	Trajectory is different than expected	3	Use fin jig to ensure angles are correct
		Fins are not symmetric			4	Shape fins to specifications before installation
Nose cone	Nose cone imperfections lead to altered trajectory	Manufacture defect	Aerodynamic forces are greater on one side of the nose cone	Trajectory is different than expected	4	Inspect nose cone and sand to correct shape
Rocket Sections	Rocket sections separate before charges ignite	Deceleration of the rocket	Sections separate early	High velocity separation	1	Make sure shear pins and screws can hold
				Premature parachute deployment at high altitudes	4	

Propulsion

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Bulkhead	Motor breaks through bulkhead	Material or construction flaws	Motor system is compromised	Motor damages rocket frame or contents	1	Inspect bulkhead prior to launch
Motor Casing	Damage to motor casing	Superficial damage	Motor is not safe if major damage occurs	Rocket is not safe to launch if damage is major	4	Check motor casing before launch, remove foreign objects from motor area
		Motor inoperable			2	
		Motor casing fracture			1	
Fuel	Contamination of fuel	Rocket fails to launch	Reduced performance of rocket motor	Rocket does not launch or perform as expected	2	Store and maintain motor fuel properly and in isolation / order from reputable source
		Over-oxidized reaction			2	
		Reduced fuel efficiency			3	
Construction	Motor misalignment	Construction or measurement error	Thrust is not in expected direction	Unpredicted trajectory	1	Check motor alignment during construction
		Rocket frame fracture			1	
Launch	Launch interference from foreign object	Unpredictable rocket trajectory	Launch when clear		3	Launch in an open area, wait for clear airspace before launch
		Rocket frame fracture			2	

Stability

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		

Cg	Expected numbers are different from actual	Error in calculations and measurements	Stability characteristics are different than projected	Flight path and characteristics in jeopardy	1	Physically measure the location of the center of gravity
Cp						Use Barrowman's method/OpenRocket to determine location of center of pressure
Static Margin						Calculate by using the locations of the center of gravity and pressure
Weight Shift	Weight shift causes center of gravity shift	Large acceleration or deceleration forces an object to shift	Static margin change due to shift in center of gravity		1	Ensure all rocket components are secure during construction process

Sample Compartment

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Door	Spring-loaded locks don't lock	Bracket misalignment	Door doesn't shut securely	Rocket is not ready to Launch. Door could open during flight and cause instability.	1	Careful inspection as part of pre-flight checklist.
		Excessive spring force required to lock			1	Calculation based on energy of required to compress spring. Tests during build process.
		Debris in lock			1	Inspection as part of pre-flight checklist.
	Hinges Fail	Excessive arm pressure			1	Tests during build process to ensure the arm behaves correctly.
		Manufacturing defect			1	Inspection and tests during build.
Sample Mold	Breaks	Excessive loading	Sample free to move and	Mission requirements not met	2	Build to withstand max force of arm.

			at risk of damage			
	Doesn't hold sample securely	Misalignment of mold			3	Inspection during pre-flight checklist.
		Sample cut out improperly sized			3	Verified during build and pre-flight checklist.
Clamps	Breaks	Excessive loading by arm			3	Visualization design needs to register proper location of clamp.
	Insufficient/excessive gripping force	Poor selection in design process			3	Testing during build and pre-flight checklist.

AGSE

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Robotic Arm	Pivot points seize	Debris	Arm can't move to retrieve sample	Failure of mission requirements	2	Inspection during pre-flight checklist.
		Binding of gears			2	Inspection during pre-flight checklist.
	Arm will not move	Rust			2	Inspection during pre-flight checklist.
		Power failure			2	Power backup as part of design.
	Unwanted movement	Signal interference			2	EMF Shielding for servo controller.
	Can't grab with claw	Gearing slips			2	Testing during build and pre-flight checklist.

Erecting System	Gearing	Structural failure	Rocket not in proper vertical position for launch.	System requires human intervention to launch.	1	Inspection during pre-flight checklist.
		Gearing slips out of plane			1	Inspection during pre-flight checklist. Monitor during competition.
		Debris in gearing			2	Inspection during pre-flight checklist.
	Motor	Over/under torqued			2	Testing during build. Monitor during competition.
	Moves beyond 5 degree from vertical	Inaccuracies in setup			2	Testing during build. Monitor during competition.
Igniter insertion system	Doesn't insert all the way	Igniter falls off rail	Failure to activate propulsion system	System requires human intervention to launch.	2	Testing during build. Monitor during competition.
		Rollers stop			2	Testing during build. Monitor during competition.
	Falls out	Cap not completely inserted			2	Inspection during pre-flight checklist.
	No ignition	Bad igniter			2	Inspection during pre-flight checklist.
		Short in wiring			2	Inspection during pre-flight checklist.
Imaging system	PVC not recognized in image	Debris on lens	Failure to capture sample autonomously	Autonomous requirement of competition is not met.	2	Inspection during pre-flight checklist.
		Focus of camera			2	Camera should be selected to be focused for small distances in competition.
		Brightness			2	Positioning of camera during competition should not be facing the sun.
	No image	Camera not detected in system			2	Camera detection as part of pre-flight checklist.

	Incorrect distance calculations	PVC in unexpected orientation	System cannot begin or stops operation.	System does not begin or ceases operation.	2	Proper' PVC placement as part of pre-flight checklist.
		PVC at a distance not in distance curve			2	Proper' PVC placement as part of pre-flight checklist.
	Power supply failure	Distribution failure			2	Testing during build process and as a part of pre-flight checklist.
		Dead batteries			1	Testing during pre-flight checklist.
		Short circuits			1	Testing during pre-flight checklist.
		Insufficient voltage supply			1	Testing during build process and as a part of pre-flight checklist.
		Insufficient current supply			1	Testing during build process and as a part of pre-flight checklist.
	BeagleBone malfunction	Reset upon a power outage			1	Testing during build process and as a part of pre-flight checklist.
	Electrical connections	Corroded connections			2	Inspection as part of pre-flight checklist.
		Loose connections pre-launch			2	Inspection as part of pre-flight checklist.
		Loose connections from launch/movement			2	Inspection as part of pre-flight checklist.
	Switches	Sticks in close/open position			2	Inspection as part of pre-flight checklist.
		Registering >1 press			2	Inspection as part of pre-flight checklist.

Appendix 3 MSDS for Hazardous Materials

GOEX Black Powder

HEALTH HAZARDS	
General	Black powder is a Division 1.1 Explosive, and detonation may cause severe physical injury, including death. All explosives are dangerous and must be handled carefully and used following approved safety procedures under the direction of competent, experienced persons in accordance with all applicable federal, state and local laws, regulation and ordinances.
Carcinogenicity	None of the components of Black Powder are listed as a carcinogen by NTP, IARC, or OSHA.

FIRST AID	
Inhalation	Not a likely route of exposure. If inhaled, remove to fresh air. If not breathing give artificial respiration, preferably by mouth-to-mouth. If breathing is difficult, give oxygen. Seek prompt medical attention. Avoid when possible.
Eye and skin contact	Not a likely route of exposure. Flush eyes with water. Wash skin with soap and water.
Ingestion	Not a likely route of exposure. If ingested, dilute by giving two glasses of water and induce vomiting. Avoid when possible.
Injury from detonation	Seek prompt medical attention.

SPILL OR LEAK PROCEDURES	
Spill/leak response	Use appropriate personal protective equipment. Isolate area and remove sources of friction, impact, heat, low level electrical current, electrostatic or RF energy. Only competent, experienced persons should be involved in clean up procedures. Carefully pick up spills with non-sparking and non-static producing tools.
Waste disposal	Desensitize by diluting in water. Open train burning, by qualified personnel, may be used for disposal of small unconfined quantities. Dispose of in compliance with Federal Regulations under the authority of the Resource Conservation and Recovery Act (40 CFR Parts 260-271).

SPECIAL PROTECTION INFORMATION	
Ventilation	Use only with adequate ventilation. (If required)
Respiratory	None
Eye	None
Gloves	Impervious rubber gloves. (If required)
Other	Metal-free and/non-static producing clothes

STORAGE CONDITIONS
Store in a cool, dry place in accordance with the requirements of Subpart K, ATF: Explosives Law and Regulations (27 CFR 55.201-55.219).

Rust-oleum

*** Emergency Overview ***: Harmful if inhaled. May affect the brain or nervous system causing dizziness, headache or nausea. Contents Under Pressure. Vapors may cause flash fire or explosion. Extremely flammable liquid and vapor. Harmful if swallowed.

Effects Of Overexposure - Eye Contact: Causes eye irritation.

Effects Of Overexposure - Skin Contact: May be harmful if absorbed through skin. Prolonged or repeated contact may cause skin irritation. Substance may cause slight skin irritation.

Effects Of Overexposure - Inhalation: High vapor concentrations are irritating to the eyes, nose, throat and lungs. Avoid breathing vapors or mists. High gas, vapor, mist or dust concentrations may be harmful if inhaled. Harmful if inhaled.

Effects Of Overexposure - Ingestion: Aspiration hazard if swallowed; can enter lungs and cause damage. Substance may be harmful if swallowed.

Effects Of Overexposure - Chronic Hazards: IARC lists Ethylbenzene as a possible human carcinogen (group 2B). May cause central nervous system disorder (e,g.,narcosis involving a loss of coordination, weakness, fatigue, mental confusion, and blurred vision) and/or damage. Reports have associated repeated and prolonged occupational overexposure to solvents with permanent brain and nervous system damage. Overexposure to xylene in laboratory animals has been associated with liver abnormalities, kidney, lung, spleen, eye and blood damage as well as reproductive disorders. Effects in humans, due to chronic overexposure, have included liver, cardiac abnormalities and nervous system damage. Overexposure to toluene in laboratory animals has been associated with liver abnormalities, kidney, lung and spleen damage. Effects in humans have included liver and cardiac abnormalities.
Contains carbon black. Chronic inflammation, lung fibrosis, and lung tumors have been observed in some rats experimentally exposed for long periods of time to excessive concentrations of carbon black and several insoluble fine dust particles. Tumors have not been observed in other animal species (i.e., mouse and hampster) under similar circumstances and study conditions. Epidemiological studies of North American workers show no evidence of clinically significant adverse health effects due to occupational exposure to carbon black.
Carbon black is listed as a Group 2B-"Possibly carcinogenic to humans" by IARC and is proposed to be listed as A4- "not classified as a human carcinogen" by the American Conference of Govermental Industrial Hygienists. Significant exposure is not anticipated during brush application or drying. Risk of overexposure depends on duration and level of exposure to dust from repeated sanding of surfaces or spray mist and the actual concentration of carbon black in the formula.

Primary Route(s) Of Entry: Skin Contact, Skin Absorption, Inhalation, Eye Contact

Section 4 - First Aid Measures

First Aid - Eye Contact: Hold eyelids apart and flush with plenty of water for at least 15 minutes. Get medical attention.

First Aid - Skin Contact: Wash with soap and water. Get medical attention if irritation develops or persists.

First Aid - Inhalation: If you experience difficulty in breathing, leave the area to obtain fresh air. If continued difficulty is experienced, get medical assistance immediately.

First Aid - Ingestion: Aspiration hazard: Do not induce vomiting or give anything by mouth because this material can enter the lungs and cause severe lung damage. Get immediate medical attention.

Section 5 - Fire Fighting Measures

Flash Point: -156 F (Setaflash)

LOWER EXPLOSIVE LIMIT: 1.0 %
UPPER EXPLOSIVE LIMIT : 9.5 %

Extinguishing Media: Dry Chemical, Foam, Water Fog

Unusual Fire And Explosion Hazards: Vapors can travel to a source of ignition and flash back. Vapors may form explosive mixtures with air. Closed containers may explode when exposed to extreme heat. Water spray may be

ineffective. FLASH POINT IS LESS THAN 20 °. F. - EXTREMELY FLAMMABLE LIQUID AND VAPOR! Perforation of the pressurized container may cause bursting of the can. Isolate from heat, electrical equipment, sparks and open flame. Keep containers tightly closed.

Special Firefighting Procedures: Evacuate area and fight fire from a safe distance.

Section 6 - Accidental Release Measures

Steps To Be Taken If Material Is Released Or Spilled: Contain spilled liquid with sand or earth. DO NOT use combustible materials such as sawdust. Remove all sources of ignition, ventilate area and remove with inert absorbent and non-sparking tools. Dispose of according to local, state (provincial) and federal regulations. Do not incinerate closed containers.

Section 7 - Handling And Storage

Handling: Wash thoroughly after handling. Wash hands before eating. Use only in a well-ventilated area. Follow all MSDS/label precautions even after container is emptied because it may retain product residues. Avoid breathing vapor or mist.

Storage: Keep containers tightly closed. Isolate from heat, electrical equipment, sparks and open flame. Do not store above 120 ° F. Store large quantities in buildings designed and protected for storage of NFPA Class I flammable liquids. Contents under pressure. Do not expose to heat or store above 120 ° F.

Section 8 - Exposure Controls / Personal Protection

Engineering Controls: Use explosion-proof ventilation equipment. Prevent build-up of vapors by opening all doors and windows to achieve cross-ventilation. Use process enclosures, local exhaust ventilation, or other engineering controls to control airborne levels below recommended exposure limits.

Respiratory Protection: A respiratory protection program that meets OSHA 1910.134 and ANSI Z88.2 requirements must be followed whenever workplace conditions warrant a respirator's use. A NIOSH/MSHA approved air purifying respirator with an organic vapor cartridge or canister may be permissible under certain circumstances where airborne concentrations are expected to exceed exposure limits.

Protection provided by air purifying respirators is limited. Use a positive pressure air supplied respirator if there is any potential for an uncontrolled release, exposure levels are not known, or any other circumstances where air purifying respirators may not provide adequate protection.

Skin Protection: Use impervious gloves to prevent skin contact and absorption of this material through the skin. Nitrile or Neoprene gloves may afford adequate skin protection.

Eye Protection: Use safety eyewear designed to protect against splash of liquids.

Other protective equipment: Refer to safety supervisor or industrial hygienist for further information regarding personal protective equipment and its application.

Hygienic Practices: Wash thoroughly with soap and water before eating, drinking or smoking.

Klean Strip Denatured Alcohol

3. Hazards Identification

Emergency Overview

Danger! Flammable! Keep away from heat, sparks, flame, and all other sources of ignition. Do not smoke. Extinguish all flames and pilot lights, and turn off stoves, heaters, electric motors and all other sources of ignition during use and until all vapors are gone. Beware of static electricity that mat be generated by synthetic clothing and other sources.

OSHA Regulatory Status: This material is classified as hazardous under OSHA regulations.

Health Hazards (Acute and Chronic)

Inhalation Acute Exposure Effects:
Vapor harmful. May cause dizziness, headache, watering of eyes, irritation of respiratory tract, irritation to the eyes, drowsiness, nausea, other central nervous system effects, spotted vision, dilation of pupils, and convulsions.

Skin Contact Acute Exposure Effects:
May cause irritation, drying of skin, redness, and dermatitis. May cause symptoms listed under inhalation. May be absorbed through damaged skin.

Eye Contact Acute Exposure Effects:
May cause irritation.

Ingestion Acute Exposure Effects:
Poison. Cannot be made non-poisonous. May be fatal or cause blindness. May produce fluid in the lungs and pulmonary edema. May cause dizziness, headache, nausea, drowsiness, loss of coordination, stupor, reddening of face and or neck, liver, kidney and heart damage, coma, and death. May produce symptoms listed under

inhalation.

Chronic Exposure Effects:
May cause symptoms listed under inhalation, dizziness, fatigue, tremors, permanent central nervous system changes, blindness, pancreatic damage, and death.

Signs and Symptoms Of Exposure

No data available.

Medical Conditions Generally Aggravated By Exposure

Diseases of the liver.

OSHA Hazard Classes:

HEALTH HAZARDS : N/E
PHYSICAL HAZARDS : N/E
TARGET ORGANS & EFFECTS: N/E

4. First Aid Measures

Emergency and First Aid Procedures

Inhalation:
If user experiences breathing difficulty, move to air free of vapors. Administer oxygen or artificial respiration until medical assistance can be rendered.

Skin Contact:
Wash with soap and water.

Eye Contact:
Flush with large quantities of water for at least 15 minutes. If irritation from contact persists, get medical attention.

Ingestion:
Call your poison control center, hospital emergency room or physician immediately for instructions to induce vomiting.

Note to Physician

Poison. This product contains methanol. Methanol is metabolized to formaldehyde and formic acid. These metabolites may cause metabolic acidosis, visual disturbances and blindness. Since metabolism is required for these toxic symptoms, their onset may be delayed from 6 to 30 hours following ingestion. Ethanol competes for the same metabolic pathway and has been used as an antidote. Methanol is effectively removed by hemodialysis. Call your local poison control center for further instructions.

5. Fire Fighting Measures

Flammability Classification:	OSHA Class IB
Flash Pt:	45.00 F Method Used: SCC
Explosive Limits:	LEL: 1.00 UEL: No data.
Autoignition Pt:	No data.

Special Fire Fighting Procedures

Self-contained respiratory protection should be provided for fire fighters fighting fires in buildings or confined area. Storage containers exposed to fire should be kept cool with water spray to prevent pressure build-up. Stay away from heads of containers that have been exposed to intense heat or flame.

Unusual Fire and Explosion Hazards

No data available.

Extinguishing Media
Use carbon dioxide, dry powder, or foam.

Unsuitable Extinguishing Media
No data available.

6. Accidental Release Measures

Steps To Be Taken In Case Material Is Released Or Spilled

Clean-up:
Keep unnecessary people away; isolate hazard area and deny entry. Stay upwind, out of low areas, and ventilate closed spaces before entering. Shut off ignition sources, keep flares, smoking or flames out of hazard area.

Small spills:
Take up liquid with sand, earth or other noncombustible absorbent material and place in a plastic container where applicable.

Large spills:
Dike far ahead of spill for later disposal.

7. Handling and Storage

Precautions To Be Taken in Handling
Read carefully all cautions and directions on product label before use. Since empty container retains residue, follow all label warnings even after container is empty. Dispose of empty container according to all regulations. Do not reuse this container.

Precautions To Be Taken in Storing
Keep container tightly closed when not in use. Store in a cool, dry place. Do not store near flames or at elevated temperatures.

8. Exposure Controls/Personal Protection

Respiratory Equipment (Specify Type)
For OSHA controlled work place and other regular users. Use only with adequate ventilation under engineered air control systems designed to prevent exceeding appropriate TLV. For occasional use, where engineered air control is not feasible, use properly maintained and properly fitted NIOSH approved respirator for organic solvent vapors. A dust mask does not provide protection against vapors.

Eye Protection
Safety glasses, chemical goggles or face shields are recommended to safeguard against potential eye contact, irritation, or injury. Contact lenses should not be worn while working with chemicals.

Protective Gloves
Wear impermeable gloves. Gloves contaminated with product should be discarded. Promptly remove clothing that becomes soiled with product.

Other Protective Clothing
Various application methods can dictate the use of additional protective safety equipment, such as impermeable aprons, etc., to minimize exposure. A source of clean water should be available in the work area for flushing eyes and skin. Do not eat, drink, or smoke in the work area. Wash hands thoroughly after use. Before reuse, thoroughly clean any clothing or protective equipment that has been contaminated by prior use. Discard any clothing or other protective equipment that cannot be decontaminated, such as gloves or shoes.

Ventilation
Use only with adequate ventilation to prevent build-up of vapors. Open all windows and doors. Use only with a cross ventilation of moving fresh air across the work area. If strong odor is noticed or you experience slight dizziness, headache, nausea, or eye-watering -- Stop -- ventilation is inadequate. Leave area immediately.

Klean Strip Acetone

3. Hazards Identification

Emergency Overview

Danger! Extremely Flammable. Keep away from heat, sparks, flame and all other sources of ignition. Vapors may cause flash fire or ignite explosively. Vapors may travel long distances to other areas and rooms away from the work site. Do not smoke. Extinguish all flames and pilot lights, and turn off stoves, heaters, electric motors and all other sources of ignition anywhere in the structure, dwelling, or building during use and until all vapors are gone from the work site. Keep away from electrical outlets and switches. Beware of static electricity that may be generated by synthetic clothing and other sources.

OSHA Regulatory Status:

This material is classified as hazardous under OSHA regulations.

Potential Health Effects (Acute and Chronic)

Inhalation Acute Exposure Effects:
Vapor harmful. May cause dizziness, headache, watering of eyes, irritation of respiratory tract, drowsiness, nausea, and numbness in fingers, arms and legs.

Skin Contact Acute Exposure Effects:
May cause drying of skin, and numbness in fingers and arms. Liquid is absorbed readily.

Eye Contact Acute Exposure Effects:
This material is an eye irritant.

Ingestion Acute Exposure Effects:
Harmful if swallowed. May cause dizziness, headache, nausea, and irritation of the mouth, throat, and stomach.

Chronic Exposure Effects:
Reports have associated repeated and prolonged overexposure to solvents with neurological and other

physiological damage. May cause weakness, fatigue, skin irritation, and numbness in hands and feet.

Signs and Symptoms Of Exposure

Primary Routes of Exposure:
Inhalation, ingestion, and dermal.

Medical Conditions Generally Aggravated By Exposure

Skin, eye, lung (asthma-like conditions)

4. First Aid Measures

Emergency and First Aid Procedures

Inhalation:
If user experiences breathing difficulty, move to air free of vapors. Administer oxygen or artificial respiration until medical assistance can be reached.

Skin Contact:
Wash with soap and water.

Eye Contact:
Flush with large quantities of water for at least 15 minutes and seek immediate medical attention.

Ingestion:
Call your poison control center, hospital emergency room, or physician immediately for instructions.

Note to Physician

Call your local poison control center for further instructions.

6. Accidental Release Measures

Steps To Be Taken In Case Material Is Released Or Spilled

Clean Up:

Keep unnecessary people away; isolate hazard area and deny entry. Stay upwind, out of low areas, and ventilate closed spaces before entering. Shut off ignition sources; keep flares, smoking or flames out of hazard area. For small spills, take up liquid with sand, earth, or other noncombustible absorbent material and place in a container for disposal. For large spills, dike far ahead of spill and use sand, earth, or other noncombustible absorbent material and then place material in a container for disposal.

Waste Disposal:

Dispose in accordance with applicable local, state, and federal regulations.

7. Handling and Storage

Precautions To Be Taken in Handling

Read carefully all cautions and directions on product label before use. Since empty container retains residue, follow all label warnings even after container is empty. Dispose of empty container according to all regulations. Do not reuse the container.

Precautions To Be Taken in Storing

Keep container tightly closed when not in use. Store in a cool, dry place. Do not store near flames or at elevated temperatures.

8. Exposure Controls/Personal Protection

Respiratory Equipment (Specify Type)

For OSHA controlled work place and other regular users. Use only with adequate ventilation under engineered air control systems designed to prevent exceeding appropriate TLV. For occasional use, where engineered air control is not feasible, use properly maintained and properly fitted NIOSH approved respirator for organic solvent vapors. A dust mask does not provide protection against vapors.

Eye Protection

Safety glasses, chemical goggles or face shields are recommended to safeguard against potential eye contact, irritation, or injury. Contact lenses should not be worn while working with chemicals.

Protective Gloves

Wear chemical resistant gloves suited for use with acetone. Gloves contaminated with product should be discarded. Promptly remove clothing that becomes soiled with product.

Other Protective Clothing

Various application methods can dictate use of additional protective safety equipment, such as impermeable aprons, etc., to minimize exposure.

Engineering Controls (Ventilation etc.)

Use only with adequate ventilation to prevent build-up of vapors. Open all windows and doors. Use only with a cross ventilation of moving fresh air across the work area. If strong odor is noticed or your experience slight dizziness, headache, nausea, or eye-watering - STOP - ventilation is inadequate. Leave area immediately.

Work/Hygienic/Maintenance Practices

A source of clean water should be available in the work area for flushing eyes and skin.
Do not eat, drink, or smoke in the work area.
Wash hands thoroughly after use.
Before reuse, thoroughly clean any clothing or protective equipment that has been contaminated by prior use.
Discard any clothing or other protective equipment that cannot be decontaminated, such as gloves or shoes.

West System 105 Epoxy Resin

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

HMIS Hazard Rating: **Health - 2** **Flammability - 1** **Physical Hazards - 0**

WARNING! May cause allergic skin response in certain individuals. May cause moderate irritation to the skin. Clear to light yellow liquid with mild odor.

PRIMARY ROUTE(S) OF ENTRY:.................... Skin contact.

POTENTIAL HEALTH EFFECTS:

ACUTE INHALATION:.................... Not likely to cause acute effects unless heated to high temperatures. If product is heated, vapors generated can cause headache, nausea, dizziness and possible respiratory irritation if inhaled in high concentrations.

CHRONIC INHALATION: .... Not likely to cause chronic effects. Repeated exposure to high vapor concentrations may cause irritation of pre-existing lung allergies and increase the chance of developing allergy symptoms to this product.

ACUTE SKIN CONTACT: .... May cause allergic skin response in certain individuals. May cause moderate irritation to the skin such as redness and itching.

CHRONIC SKIN CONTACT:.................... May cause sensitization in susceptible individuals. May cause moderate irritation to the skin.

EYE CONTACT: .... May cause irritation.

INGESTION:.................... Low acute oral toxicity.

SYMPTOMS OF OVEREXPOSURE: .... Possible sensitization and subsequent allergic reactions usually seen as redness and rashes. Repeated exposure is not likely to cause other adverse health effects.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE:.................... Pre-existing skin and respiratory disorders may be aggravated by exposure to this product. Pre-existing lung and skin allergies may increase the chance of developing allergic symptoms to this product.

4. FIRST AID MEASURES

FIRST AID FOR EYES.................... Flush immediately with water for at least 15 minutes. Consult a physician.

FIRST AID FOR SKIN.................... Remove contaminated clothing. Wipe excess from skin. Remove with waterless skin cleaner and then wash with soap and water. Consult a physician if effects occur.

FIRST AID FOR INHALATION.................... Remove to fresh air if effects occur.

FIRST AID FOR INGESTION.................... No adverse health effects expected from amounts ingested under normal conditions of use. Seek medical attention if a significant amount is ingested.

6.	ACCIDENTAL RELEASE MEASURES

SPILL OR LEAK PROCEDURES: .... Stop leak without additional risk. Dike and absorb with inert material (*e.g.*, sand) and collect in a suitable, closed container. Warm, soapy water or non-flammable, safe solvent may be used to clean residual.

7.	HANDLING AND STORAGE

STORAGE TEMPERATURE (min./max.): .... 40°F (4°C) / 120°F (49°C)

STORAGE: .... Store in cool, dry place. Store in tightly sealed containers to prevent moisture absorption and loss of volatiles. Excessive heat over long periods of time will degrade the resin.

HANDLING PRECAUTIONS: .... Avoid prolonged or repeated skin contact. Wash thoroughly after handling. Launder contaminated clothing before reuse. Avoid inhalation of vapors from heated product. Precautionary steps should be taken when curing product in large quantities. When mixed with epoxy curing agents this product causes an exothermic, which in large masses, can produce enough heat to damage or ignite surrounding materials and emit fumes and vapors that vary widely in composition and toxicity.

8.	EXPOSURE CONTROLS/PERSONAL PROTECTION

EYE PROTECTION GUIDELINES: .... Safety glasses with side shields or chemical splash goggles.

SKIN PROTECTION GUIDELINES: .... Wear liquid-proof, chemical resistant gloves (nitrile-butyl rubber, neoprene, butyl rubber or natural rubber) and full body-covering clothing.

RESPIRATORY/VENTILATION GUIDELINES: .... Good room ventilation is usually adequate for most operations. Wear a NIOSH/MSHA approved respirator with an organic vapor cartridge whenever exposure to vapor in concentrations above applicable limits is likely.

Note: West System, Inc. has conducted an air sampling study using this product or similarly formulated products. The results indicate that the components sampled for (epichlorohydrin, benzyl alcohol) were either so low that they were not detected at all or they were significantly below OSHA's permissible exposure levels.

ADDITIONAL PROTECTIVE MEASURES: .... Practice good caution and personal cleanliness to avoid skin and eye contact. Avoid skin contact when removing gloves and other protective equipment. Wash thoroughly after handling. Generally speaking, working cleanly and following basic precautionary measures will greatly minimize the potential for harmful exposure to this product under normal use conditions.

OCCUPATIONAL EXPOSURE LIMITS: .... Not established for product as whole. Refer to OSHA's Permissible Exposure Level (PEL) or the ACGIH Guidelines for information on specific ingredients.

West System 206 Hardener

2.	HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

DANGER Causes burns to eyes and skin. Harmful if swallowed. Harmful if absorbed through the skin. May be harmful if inhaled. Can cause allergic reaction. Aspiration hazard. Clear liquid with ammonia odor.

PRIMARY ROUTE(S) OF ENTRY: .... Skin and eye contact, inhalation.

POTENTIAL HEALTH EFFECTS:

ACUTE INHALATION: .... Excessive exposure to vapor or mist is irritating to the upper respiratory tract, causing nasal discharge, coughing, and discomfort in eyes, nose, throat and chest. Severe cases may cause difficult breathing and lung damage.

CHRONIC INHALATION: .... May cause lung damage. May cause respiratory sensitization in susceptible individuals. Repeated exposures may cause internal organ damage.

ACUTE SKIN CONTACT: .... Corrosive. Prolonged contact may cause skin damage with burns and blistering. Wide spread contact may result in material being absorbed in harmful amounts.

CHRONIC SKIN CONTACT: .... May cause persistent irritation or dermatitis. Repeated contact may cause allergic reaction/sensitization and possible tissue destruction. Can be absorbed through the skin in amounts that can cause internal organ damage.

EYE CONTACT: .... Corrosive. May cause blurred vision. May cause irritation with corneal injury resulting in permanent vision impairment or even blindness.

INGESTION: .... Moderately toxic. May cause gastrointestinal irritation or ulceration. May cause burns of the mouth and throat. Aspiration hazard.

SYMPTOMS OF OVEREXPOSURE: .... Skin irritation, burns and blistering. Irritation of the nose and throat, possible headache. Eye irritation and blurred vision.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: .... Existing respiratory conditions, such as asthma and bronchitis. Existing skin conditions.

4. FIRST AID MEASURES

FIRST AID FOR EYES: .... Immediately flush with water for at least 15 minutes. Get prompt medical attention.

FIRST AID FOR SKIN: .... Remove contaminated clothing. Immediately wash skin with soap and water. Do not apply greases or ointments. Get medical attention if severe exposure.

FIRST AID FOR INHALATION: .... Move to fresh air and consult physician if effects occur.

FIRST AID FOR INGESTION: .... Give conscious person at least 2 glasses of water. Do not induce vomiting. Aspiration hazard. If vomiting should occur spontaneously, keep airway clear. Get medical attention.

6. ACCIDENTAL RELEASE MEASURES

SPILL OR LEAK PROCEDURES: .... Stop leak without additional risk. Wear proper personal protective equipment. Dike and contain spill. Ventilate area. Large spill - dike and pump into appropriate container for recovery. Small spill - recover or use inert, non-combustible absorbent material (*e.g.*, sand, clay) and shovel into suitable container. Do not use sawdust, wood chips or other cellulosic materials to absorb the spill, as the possibility for spontaneous combustion exists. Wash spill residue with warm, soapy water if necessary.

7. HANDLING AND STORAGE

STORAGE TEMPERATURE (min./max.): .... 40°F (4°C) / 90°F (32°C).

STORAGE: .... Store in cool, dry place with adequate ventilation.

HANDLING PRECAUTIONS: .... Use only with adequate ventilation. Do not breath vapors or mists from heated material. Avoid contact with skin and eyes. Wash thoroughly after handling. When mixed with epoxy resin this product causes an exothermic reaction, which in large masses, can produce enough heat to damage or ignite surrounding materials and emit fumes and vapors that vary widely in composition and toxicity.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

EYE PROTECTION GUIDELINES: .... Chemical splash goggles, full-face shield or full-face respirator.

SKIN PROTECTION GUIDELINES: .... Wear liquid-proof, chemical resistant gloves (nitrile-butyl rubber, neoprene, butyl rubber or natural rubber) and full body-covering clothing.

RESPIRATORY/VENTILATION GUIDELINES: .... General mechanical or local exhaust ventilation. With inadequate ventilation, use a NIOSH/MSHA approved air purifying respirator with an organic vapor cartridge.

Note: West System, Inc. has conducted an air sampling study using this product or similarly formulated products. The results indicate that the components sampled for (amines) were either so low that they were not detected at all or they were well below OSHA's permissible exposure levels.

ADDITIONAL PROTECTIVE MEASURES: .... Use where there is immediate access to safety shower and emergency eye wash. Provide proper wash/cleanup facilities for proper hygiene. Contact lens should not be worn when working with this material. Generally speaking, working cleanly and following basic precautionary measures will greatly minimize the potential for harmful exposure to this product under normal use conditions.

OCCUPATIONAL EXPOSURE LIMITS: .... Not established for product as whole. Refer to OSHA's Permissible Exposure Level (PEL) or the ACGIH Guidelines for information on specific ingredients.

J-Tek Electric Matches

Material Safety Data Sheet

NOTICE

ALL INFORMATION APPEARING HEREIN IS BASED UPON DATA OBTAINED FROM THE MANUFACTURER AND/OR RECOGNIZED TECHNICAL SOURCES. THIS INFORMATION IS BELIEVED TO BE CORRECT, BUT DOES NOT PURPORT TO BE ALL INCLUSIVE AND SHALL BE USED ONLY AS A GUIDE. MJG TECHNOLOGIES INC. MAKES NO WARRANTY, EXPRESS OR IMPLIED, AS TO THE ACCURACY OR COMPLETENESS OF THIS INFORMATION. IT IS THE USER'S RESPONSIBILITY TO DETERMINE THE SUITABILITY OF THIS INFORMATION FOR THE ADOPTION OF NECESSARY SAFETY PRECAUTIONS AND/OR COMPLIANCE WITH LOCAL, STATE, AND FEDERAL LAWS AND REGULATIONS.

Section I. - General Information

Identity: *(As used on label and list)*
UN0454 Igniters 1.4S
Manufacturer's Name & Address:
MJG Technologies, Inc.
832 Camden Avenue
Blenheim, NJ 08012

Trade Name: J-Tek
Emergency Telephone: 1-800-535-5053 Contract # 100588
Telephone Number: 856-228-6118
Date Prepared: February 21, 2011
Prepared By: J. Genzel

Section II. - Hazardous Ingredients / Identity Information

Per OSHA 29 CFR 1910.1200 — **Exposure Limits**

Chemical Name:	**CAS#**	OSHA (PEL)	ACGIH (TLV)	**Other Limits %**
Bismuth Trioxide	1304-76-3	15 mg / m3	10mg / m3	
Boron	7440-42-8	15 mg / m3	10mg /m3	orl rat LDLo; 32g/kg/30 days
Potassium Perchlorate	7778-74-7	Not Established	Not Established	orl rat LDLo: 2,100 mg/kg
Titanium	7440-32-6	Not Established	Not Established	ims-rat LDLo:114 mg/kg/77W-1

Section III. - Physical / Chemical Characteristics

Boiling Point (deg. F.) N/A

Vapor Pressure (mm Hg.) N/A

Vapor Density (Air = 1) N/A

Specific Gravity (H_2O = 1) N/A

Melting Point N/A

Evaporation Rate (Butyl Acetate = 1) N/A

Solubility in Water: Insoluble with lacquer coating intact.

Appearance and Odor: Medium brown colored bead of pyrotechnic composition on a copper-clad chip with two PVC insulated connecting wires of various lengths. Red or blue lacquer coating on igniter head.

Section IV. - Fire and Explosion Hazard Data

Flash Point: N/A

Flammable Limits N/A **LEL** N/A **UEL** N/A

Extinguishing Media: N/A

Special Fire Fighting Procedures: Do not use suffocating methods - devices contain their own oxygen. If conditions permit, separate burning from unburned igniters.

Unusual Fire and Explosion Hazards: Burning igniters will project sparks several feet and can cause secondary fires. Igniters may rupture a container if ignited under confinement. Igniters may be ignited by extreme impact, friction or electrostatic discharge.

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Section V. - Reactivity Data

Stability: Stable **Conditions To Avoid:** Sources of ignition - heat, sparks, open flames and smoking. Do not subject igniter heads to impact or friction.
Incompatibility (Materials to Avoid): Acids and reducing agents.
Hazardous Decomposition or Byproducts: Smoke contains oxides of Boron and Titanium.
Hazardous Polymerization: Will not occur.

Section VI. - Health Hazard Data

Route(s) of Entry:	Inhalation?	Skin?	Ingestion?
	Not with match head intact.	No	Not with match head intact.

Health Hazards (Acute and Chronic): Primary hazard is from thermal burns caused by accidental ignition of igniters Deliberate inhalation or ingestion of large amounts of crushed igniter head composition may cause respiratory discomfort. Not absorbed through skin.

Carcinogenicity:	NTP?	ARC Monographs?	OSHA Regulated?
	No	No	No

Signs and Symptoms of Exposure: See Boric Acid exposure. Large doses of Boron compounds can cause depression of the circulation, persistent vomiting and diarrhea, followed by shock and coma.
Bismuth Trioxide ingestion has no known adverse effects. However, ingestion is not advised.

Medical Conditions Generally Aggravated By Exposure: Smoke generated by burning igniters may cause respiratory irritation in those individuals with asthma, allergies or other preexisting respiratory conditions.

Emergency First Aid Procedures: Move patient to source of fresh air. Do not induce vomiting. Get prompt medical attention from qualified medical personnel.

Section VII. - Precautions For Safe Handling And Use

Steps To Be Taken In Case Material Is Released Or Spilled: Immediately remove sources of ignition and isolate spill from any other flammable or pyrotechnic materials. Sweep up any crushed igniter heads using non-sparking tools. Avoid inhaling igniter head dust.

Waste Disposal Method: Dispose of in accordance with local, state and federal regulations. Small quantities can be disposed of by open burning if permitted.

Precautions To Be Taken In Handling And Storage: Keep away from sources of heat and ignition, such as sparks or open flames. Avoid impact or friction to match head. Store igniters in accordance with local, state and federal regulations. Keep dry and avoid temperatures above 120 F. Keep out of the reach of children and uniformed persons.

Other Precautions: Avoid sources of strong electromagnetic fields and static electricity. Do not pick up with a vacuum cleaner

Section VII. - Control Measures

Respiratory Protection (Specify Type): Nuisance dust/particulate filter mask if large numbers of igniters are ignited in a confined area.
Ventilation: Yes. **Local Exhaust:** Acceptable.
Mechanical (General): **Special:**
Protective Gloves: Not normally required. **Other:**
Eye Protection: Goggles or safety glasses with side shields.
Other Protective Clothing or Equipment: Long sleeve cotton garments advised if handling a large quantity of igniters.
Work / Hygienic Practices: Wash thoroughly after handling igniters and before eating, drinking or smoking.

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Appendix 4 Photo References

Figure 29 AGSE Robotic Arm: http://www.robotshop.com/en/robotshop-m100rak-v2-modular-robotic-arm-kit-no-electronics.html
Figure 30 Gripper Used on the Arm: http://www.robotshop.com/en/lynxmotion-little-grip-kit.html
Figure 34 Planetary Geared Stepper Motor Used to Raise Launch Rail: http://www.omc-stepperonline.com/gear-ratio-471-planetary-gearbox-nema-23-geared-stepper-motor-23hs222804spg47-p-147.html
Figure 35 Igniter Insertion System: http://www.omc-stepperonline.com/nema-17-bipolar-stepper-12v-04a-40ncm567ozin-17hs150404s-p-14.html
Figure 37 Sentech USB 2.0 Camera: http://www.sentechamerica.com/En/Cameras/USB/STC-MC36USB
Figure 38 Unprocessed PVC on Grass Picture: http://cdn.instructables.com/FBS/FBJX/FYIZ53KF/FBSFBJXFYIZ53KF.MEDIUM.jpg